The development of a farmer decision-making mind map to inform climate services in Central America

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EDITED BY
Ajay Bhave,
University of Leeds, United Kingdom

REVIEWED BY
Andrew John Dougill,
University of Leeds, United Kingdom
Gabriela Cruz,
Universidad de la República, Uruguay
Diana Ruiz,
University of Cauca, Colombia

*CORRESPONDENCE
Diana Giraldo
✉ d.c.giraldo@pgr.reading.ac.uk

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The development of a farmer decision-making mind map to inform climate services in Central America

Diana Giraldo[1,2]*, Graham Clarkson[1], Peter Dorward[1], Diego Obando[3] and Julian Ramirez-Villegas[4,5,6]

[1]School of Agriculture, Policy and Development, University of Reading, Reading, United Kingdom, [2]International Center for Tropical Agriculture, Cali, Colombia, [3]International Center for Tropical Agriculture, Tegucigalpa, Honduras, [4]International Center for Tropical Agriculture (CIAT), c/o Bioversity International, Rome, Italy, [5]Bioversity International, Rome, Italy, [6]Plant Production Systems Group, Wageningen University & Research, Wageningen, Netherlands

The growing complexity of the relationship between climate information and agricultural decision-making necessitates the development of relevant and timely climate services for farmers. These services can effectively support risk management strategies in agriculture by fostering a comprehensive understanding of the intricacies involved in farmer decision-making dynamics. This paper addresses this critical gap by analyzing the drivers influencing decision-making processes that shape adaptation strategies for staple grain and coffee farming systems in Central America. The study answers the following research questions: (i) Does the mind map tool effectively provide a holistic understanding of farmers' decision-making processes? (ii) How do Central American farmers make decisions within their farm systems at multiple timescales? (iii) Which climate factors trigger these decisions? Employing a combination of systematic literature review and a case study in Honduras, the study identifies 13 critical decisions farmers make throughout their crop cycle and their respective triggers. These decisions were grouped into three clusters (production, household, and environmental) and classified into lead-time categories (operational, tactical, and strategic). Findings reveal that farmers base their decisions regarding future climate expectations on their traditional knowledge, religious dates, and memories of recent past seasons' rainfall patterns, and that one of the most significant factors influencing farmers' decisions is food security shortages resulting from extreme events. For example, recent mid-summer droughts have led farmers to prioritize sowing beans over maize in the *Primera* season, while during the *Postrera* season, they face challenges due to excess rainfall and the hurricane season. We conclude that the mind map tool developed in this paper provides an effective and appropriate method and that the variation in farmers' decision-making complexity across systems and landscapes presents a significant opportunity to design mind maps that span multiple timescales, facilitating the exploration of decision spaces. Farmers actively seek tailored weather and climate information while still valuing their existing experience and local knowledge, emphasizing the importance of integrating these elements into the development of climate services.

KEYWORDS

decision-making, climate services, risk management, dry corridor, systems thinking

1. Introduction

Over the last century, prolonged droughts, shifting rainfall patterns and extreme events have significantly impacted Central America, where more than two-thirds of the population depends on agriculture (Imbach et al., 2017). Climate variability and change, with a variety of other local stressors, can motivate a shift in strategy in farmers' decision-making, such as planting a new crop, experimenting with a new variety, or migration of a household member (Eakin et al., 2014). The literature recognizes that farmer decision-making is highly dynamic and complex, and is influenced by social relations, individual experiences and their context (Soares et al., 2018). Farmers are constantly making decisions about what, when, and where to plant, management practices and about resource allocation to farm activities such as livestock and other livelihoods. Climate services can create opportunities to better integrate local knowledge and scientific information into the decision-making process (Guido et al., 2021). Climate services are defined as the processes that involve the production, translation, transfer, and use of weather and climate information, all aimed at enabling and informing effective decision-making (Born et al., 2021).

In Central America, previous studies have analyzed farmers' responses to various climate-related changes including hurricanes (Alayón-Gamboa et al., 2011; Cruz-Bello et al., 2011), El Niño droughts (Ewbank et al., 2019), interannual climate variability (Eakin, 2000), and climate change (Harvey et al., 2017, 2018; Bielecki and Wingenbach, 2019; Gerlicz et al., 2019). Individually, these studies typically help identify what events affect farmers, and decisions are (or should be) made in response to such events, with only limited attempts to establishing a link between the decisions and the broader spatio-temporal and socioeconomic context. There is thus a significant gap in the literature on (i) how Central American farmers make decisions within their farm system at multiple timescales, (ii) the climate factors that trigger those decisions, and (iii) how to map farmers' decision-making dynamics together with their farming and support systems for climate services development.

To address these gaps, we chose a systems thinking approach to gain a more holistic understanding of farmers' decision-making in Central America. Systems thinking can be classified under "hard" or "soft" approaches (Darnhofer et al., 2012; Rose et al., 2018). Hard approaches tend to rely on mathematical or economic models based primarily on utility maximization outcomes (e.g., income, cost-benefit, or highest yields) and are driven by assumptions that farmers have full access to information (e.g., on seeds, soil, climate) and make decisions on a single time frame (e.g., a production cycle), thus simplifying assumptions of human behavior in the decision-making process. Soft systems, on the other hand, view decision-making with a focus on decisions as processes rather than just a set of well-defined outcomes (Frisch and Clemen, 1994). They allow more holistic enquiry and understanding (Singh et al., 2016), and place emphasis on decision rules and social appraisals, mind maps and ontologies, traditional ecological knowledge and adaptive pathways (Darnhofer et al., 2012).

Soft systems thinking has not been used so far to inform the development of climate services in Central America. Climate services are considered by many providers to be the delivery of higher-quality data (e.g., information and products) rather than to provide an integrated process for improved decision-making (Lourenço et al., 2015; Findlater et al., 2021), involving and encouraging users to make their own decisions based on the analysis of information and their demands. Indeed, the generation of output or product may not be as important as the process itself. The definition of climate services, as provided by Findlater et al. (2021), has shifted the focus from solely providing information to emphasizing the importance of understanding the processes behind decision-making, including who is involved and why and how decisions are made. This represents a significant paradigm shift in the field of climate services.

Here, we aim to first understand Central American farmer decision-making and then explore how this understanding can be integrated into the development of climate services. A "holistic picture" of farmers' decision-making was created using the mind map approach, which combined the results of a literature review through a set of framing questions and a case study conducted with farmers and crop experts in the field in Honduras. Our study aims to help fill the knowledge gap on farmers' decision-making in Central America by (i) documenting whether and how specific decisions are triggered by weather and climate variables; and (ii) what weather and climate information are required to support decision-making by small-scale farmers who cultivate coffee, maize and beans in Central America. We conclude by discussing the implications of the results within the context of climate services for agriculture.

2. Materials and methods

2.1. Study area

Our study area is the Central American Dry Corridor (CADC)—a drought-prone area, mainly in Guatemala, El Salvador, Honduras, and Nicaragua (herein referred to as CA4 countries). Climate in the CADC is semi-arid, with two rainy seasons, divided by a long dry season, and a mid-summer drought or *canícula*. Variations in temperature and precipitation trigger severe droughts and short dry spells, which impact farming systems and food security (Alpízar et al., 2020). According to PRESANCA and the FAO (2011), there are 2.3 million small-scale farmers in the Central American Dry Corridor. The CA4 countries have two main small-scale farming systems: basic grains (maize and beans) and small-scale coffee production. Bouroncle et al. (2017) offer a review of agricultural statistics in the area and report that the most important cash and subsistence crops in terms of cultivated area are maize (34%), coffee (16%), beans (14%), followed by sugar cane (8.4%), rice (5.8%), and sorghum (4.9%). Figure 1 shows livelihood zones in the CADC, which integrate economic activities and farming systems within each CA4 country (Grillo and Holt, 2009).

The landscapes in the livelihoods zone map include rain-fed coffee and basic grain production. Basic grains are produced under the *milpa* system (Olson et al., 2012 and Hellin et al., 2017), with average farm sizes ranging from 0.9 to 4.5 ha (Bokusheva et al., 2012; Alpízar et al., 2020; Baumann et al., 2020). In the coffee (*Coffea arabica L.*) zones, namely GT11, SV02, HN05, and NI12, the annual rainfall ranges between 1,000 and 2,000 mm,

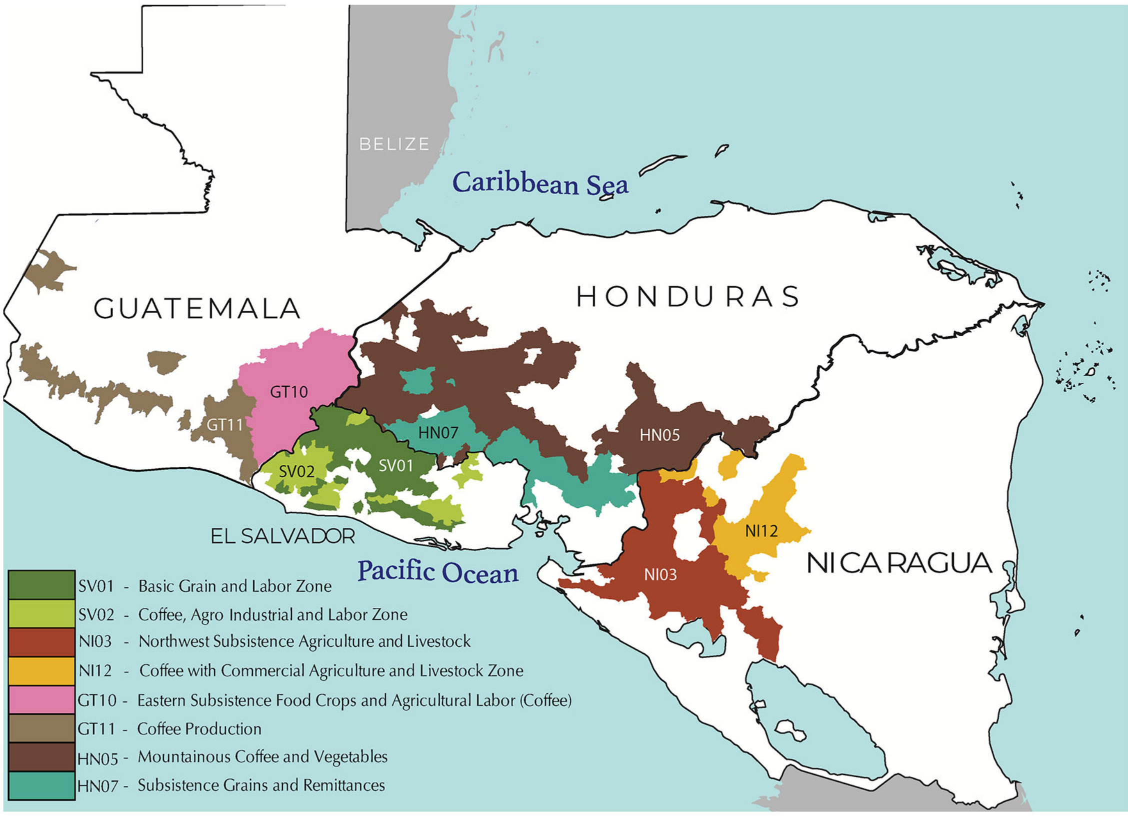

FIGURE 1
Livelihoods zone map for the productive systems of interest considered in the systematic literature review in El Salvador (SV), Nicaragua (NI), Guatemala (GT), and Honduras (HN) (data source: FEWS NET, 2007).

while the temperature ranges between 12 and 28°C. In the zones of the subsistence grains maize (*Zea mays*) and beans (*Phaseolus vulgaris*), namely GT10, SV01, HN07, and NI03, the annual rainfall ranges between 800 and 1,500 mm, while the temperature ranges between 21 and 30°C. Mean household head age is 47.8 years and a mean household size of five to six members (Hellin et al., 2017; Dodd et al., 2020). Furthermore, household heads generally have a low level of formal education (i.e., have not completed primary school) and limited access to technical support (Eakin et al., 2014). According to FEWS NET (2007), the income sources in livelihood zones are from sales of crops (i.e., basic grains, coffee, and fruits), livestock, and firewood; migration to sugar cane and coffee areas for harvest seasons; and remittances.

2.2. Agro-climatic calendars

A critical aspect of the decision-making is the timing of decisions with respect to the productive cycle of the crops, and the local agroecosystem dynamics. In the CA4 region, climate services for agriculture that support farmer decision-making have concentrated more on seasonal to decadal climate information through the Climate Outlook Forum (Garcia-Solera and Ramirez, 2015) than on weather timescales (i.e., hours to days). However, this neglects the fact that the production systems involve a sequence of interrelated decisions at multiple timescales. The study thus starts from understanding the full extent of farming system dynamics across time, to then create links at all relevant temporal scales through the mind map. To this aim, agro-climatic calendars were developed for the two systems in question (coffee and maize/beans) through a comprehensive literature review to identify the crop cycles that are commonly used in the CA4. The calendars were then refined and validated through consultation with experts (field officers) and small-scale farmers, providing a better understanding of the context.

2.3. The mind map tool

A mind map is a tool for organizing ideas and identifying thematic groups that show interconnections between ontologies—the distinction of different types of existing knowledge and their elements, concepts and relations (Buzan and Buzan, 2006). The mind map is a non-formal representation of ontologies that can then evolve into a semi-formal (e.g., Unified Modeling Language—UML) or a more formal Ontology Web Language (OWL) structure (Husáková and Bureš, 2020). Mind maps have been used to understand farmer decision-making in several sectors and countries including biodiversity conservation in Australia (Farmar-Bowers and Lane, 2009) and crop production in Ethiopia

TABLE 1 Description of the competency questions (CQs) with examples.

CQs	Description	Example
DN	The question that defines the decision made by the farmer	What variety of maize do I plant? Early maturing variety?
DT	The type of decision (strategic, tactical, or operational)	Tactical (medium-term)
	When do farmers make the decisions	April
	The trigger event that results in the decision process being an action	Prolonged drought, seed availability
IN	Information required to help make the decision	Midsummer drought "canicula," rainfall forecast, soil information
DM	The person responsible for making the decision	The man and the woman in the household

DN, decision name; DT, decision type; IN, information needs; DM, decision maker.

(Kraaijvanger et al., 2016), Sri Lanka (Walisadeera et al., 2015), Nepal (Afzal and Kasi, 2019), and Thailand (Kawtrakul, 2012).

To define the purpose and scope of the mind map four Competency Questions (CQs, Walisadeera et al., 2015; Table 1) were determined. This enabled the necessary information to be obtained from the literature review as well as in the case study. The *Decision Name (DN)* encompasses the critical decisions that farmers make in their crop cycle, ranging from why they plant their crops to whether they harvest for the market or consumption. The *Decision Type (DT)* allowed us (i) to classify decisions into lead-time categories, namely short-term operational decisions (days to weeks; e.g., land preparation), tactical medium-term decisions (months; e.g., crop selection), and strategic medium- to long-term decisions (a year or more; e.g., selection of irrigation system); (ii) to determine decision timing (e.g., the month or crop stage when a decision is made); and (iii) to identify trigger events (e.g., prolonged droughts) that influence farmers' decision-making processes (Fountas et al., 2006; Hollinger, 2009; Prokopy et al., 2013; Robert et al., 2016). The *Information Needs (IN)* encompasses the information required for making decisions (e.g., rainfall forecast). Lastly, the fourth CQ pertained to the *Decision Maker (DM)*, allowing us to understand the roles of different household members in the decision-making processes (Rose et al., 2018).

2.4. Data collection and analysis

We chose a systems thinking approach—mind map tool—to gain a more holistic understanding of farmers' decision-making. This approach integrates a systematic literature review and a mind mapping tool to better comprehend these processes through qualitative analysis (Figure 2). The first three steps of the data collection and analysis process (steps 1–3) relates to compiling and systematizing the literature sources, whereas step 4 focuses on building a first mind map, and then enriching it with case study information. To create the case study, we used qualitative techniques (i.e., interviews, focus groups and observations) to increase the study's internal validity, aiming to develop a holistic picture of the farmer's decision-making. We applied the mind map to the main crops in the CA4 countries—maize, beans, and coffee, structuring the process along the four Competency Questions (CQs) shown in Table 1.

2.4.1. Step 1–identification

Relevant literature was examined to identify common vocabulary for the mind map through web searches with different combinations of keywords connected with the AND-OR operators, including "farmersm," "decision-making," "coffee," "maize," "bean," "Central America," "dry corridor," and "climate services," using Google Scholar and Web of Science. Only peer-reviewed articles, books, and dissertations published from 2000 to 2020 in English or Spanish were included in the review. Snowball sampling was employed to identify additional literature cited within the initial search. This process resulted in the identification of 74 articles in Central America.

2.4.2. Step 2–screening

Next, we assessed articles for inclusion based on their abstract using three criteria (see Supplementary Table S1 for a list of the criteria). An essential criterion for inclusion was that each article involved collection of primary data in the field with farmers through surveys, interviews, or participatory approaches. The final list of 31 selected references that address used for the analysis are shown in Supplementary Table S2.

2.4.3. Step 3–systematic analysis

In this step, we first performed a descriptive analysis of the abstracts using word clouds in NVivo 12 (Zhou et al., 2016; see Supplementary Figure S1). The word clouds allowed analyzing the frequency of certain words and are especially useful if one can identify some of the decisions for each system in the study area (e.g., cultivars and diversification) as well as some factors that influence such decisions (e.g., seasonal variability, hurricane, and coffee rust). Next, the articles were classified and coded in nodes using NVivo 12, requiring close reading and interpretation on the researcher's part. In NVivo 12, a node refers to a collection of references that deal with a specific topic and are used to group articles (Verdonck et al., 2015). In this paper, each node represented a classification according to each CQs (Table 1), and certain paragraphs of an article were assigned to a specific node.

2.4.4. Step 4–the mind map

We constructed a first version of the mind map using three inputs from the literature review, (i) the key decisions that the farmers make in their farm system, (ii) when those decisions are

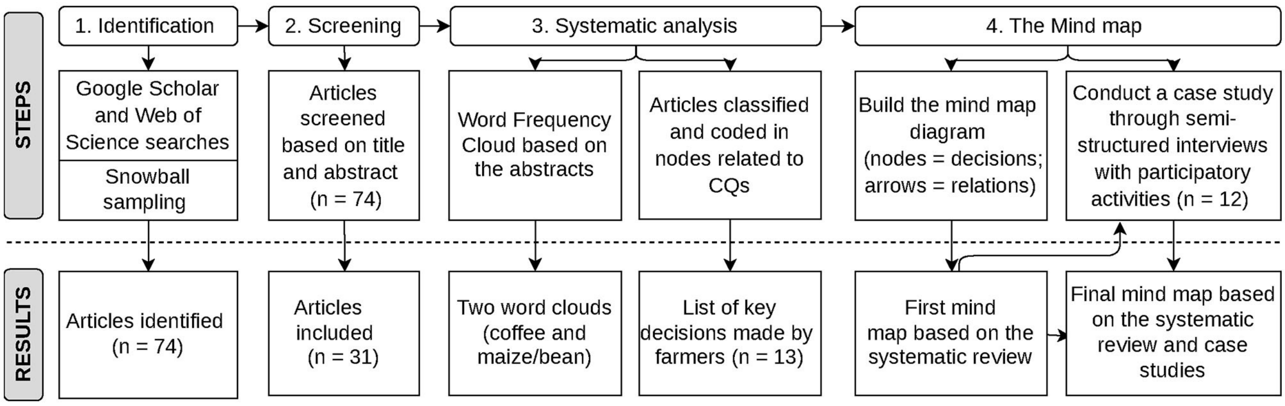

FIGURE 2
Schematic representation of the mind map process.

made and who by, and (iii) the information and relations to the weather and climate variables that trigger those decisions. The key decisions identified are the nodes in the mind map and the arrows are the relations with the other CQs. After the first version of the mind map was completed, a case study was conducted with field officers ($n = 5$) and farmers ($n = 7$) in 2021. The case study involved nine interviews and three focus groups in which participants were purposively and snowball-selected in Honduras due to their well-known experience and knowledge of coffee and basic grain systems (Table 2). No other characteristics were taken into account for the selection. The snowball selection consisted of first identifying field officers as participants, and then asking them to identify at least two farmers' associations. For the farmers, they were asked to identify at least three individual farmers. This process was repeated three times until at least 15 participants were identified. We involved these domain "experts" in the field to verify and address any gaps in the mind map. They provided advice/input on the following two aspects of the first version of the mind map: (i) the contents–decisions and (ii) structure–relations. The case study involved semi-structured interviews and focus groups (∼2 h) for answering the CQs (see Supplementary material for the case study protocol).

The case study involved open questions: When and why did you start planting beans/maize/coffee? When did you plant the crop? How has the crop been in recent years? Second, the interviewees were asked to draw an agro-climatic calendar with the specific activities that they perform on their crop, how these activities have been affected by weather and climate, and the role of family members in them. Finally, the decisions list identified from the literature was used to ask the interviewees whether they identified them as relevant and why. They were also asked whether any decision was missing, as well as what information they would require to make better decisions. The interviews and focus groups were conducted in Spanish in July and August 2021. The case study protocol was approved by the University of Reading's Research Ethics Committee. The transcripts from the sets of interviews were coded and analyzed with NVivo 12 following the same process as for the systematic review. For the synthesis, a qualitative content analysis was conducted linked to the CQs. The mind maps were built using the Mindmaster tool (Edrawsoft, 2022).

3. Results

3.1. Key decisions made by farmers

Table 3 presents the maize/beans and coffee agro-climatic calendars based upon the literature review and the case study. Small-scale farmers in the CA4 region generally grow the first crop—maize—at the beginning of the rainy season (i.e., late May or early June) and harvest it in October, locally called the *Primera* season. By contrast, the second crop—beans—is planted regularly during the growing seasons of September–December and December–March, locally called the *Postrera* and *Apante* seasons, respectively (Hellin and Schrader, 2003 and Baumann et al., 2020; Ibáñez et al., 2022). In addition, the most frequently reported lean months—June, July, and August—coincide with the Mid-Summer Drought (MSD, known as "*canicula*"), and are associated with a lack of income (Bacon et al., 2014). Maize and beans have an approximate cycle length of 3–5 and 2–3 months, respectively. The process is divided into four phenological phases, from planting and germination to harvesting. Coffee production is divided into six phases, from germination and seedling to harvesting (Table 3). The exact length of the cycle and timing of the phases vary according to the variety, environmental conditions, and crop management (Bacon et al., 2014). Moreover, as coffee is a perennial crop, the vegetative and reproductive growth phases may occur simultaneously but in different plots on the same farm. The lifespan of a coffee plantation can be up to 30 years (Bunn et al., 2015).

As a result of the systematic literature review, relevant information to answer the CQs were found. We identified the decisions that farmers make in their production systems, the timing of these decisions, and the factors that influence them. However, most articles have addressed only a particular decision without a holistic view of the farming system and the roles of household members in the decision-making processes. A total of 13 decisions triggered by weather or climate events were found in the 31 articles from the CA4 countries (Table 4). The decisions were grouped into the following three clusters, *Cluster A:* Production system, which comprised decisions related directly to maintaining or improving crop production; *Cluster B:*

TABLE 2 Case study with key informant interviews and focus groups in Honduras.

ID	Farmer interviews	ID	Field officers interviews	Total
FBean01	Bean farmer	FOBean01	Bean field officer	9
FMaize02	Maize farmer	FOMaize02	Maize field officer	
FCoffe01	Coffee farmer	FOCoffee01	Coffee field officer	
FCoffe02	Coffee farmer	FOCoffee02	Coffee field officer	
FCoffe03	Coffee farmer			
ID	**Farmer focus groups**	**ID**	**Field officers focus groups**	**Total**
FFGWA01	Women association	FFGCA01	Coffee association	3
FFGFA02	Farmers association			

TABLE 3 Summary of the CA4 countries typical maize/beans and coffee small-scale farmers seasonal calendars based upon the literature review and experts in the field.

					1st rainy season			MSD	2nd rainy season			
Maize/bean stages	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Land preparation			Maize	Maize								
Planting and germination					Maize	Maize			Beans			
Vegetative growth							Maize			Beans		
Reproductive growth								Maize	Maize		Beans	
Harvesting									Maize	Maize		Beans
Coffee stages*												
Germination and seedling	■ **	■	■									
Vegetative growth			■	▣	■	■	■	■	■	■	■	■
Reproductive and dormancy	■	■										
Main flowering	■	■	■	■								
Fruit development				▣	■	■	■	■	■			
Maturation and harvesting	■									■	■	■

MSD, mid-summer drought.
*Representation of the first and second phenological years.
**The germination and seedling stage can take as long as 6 months. Maize Beans.

Household strategies, which comprised decisions linked to family projects or collaborative networks for reducing vulnerabilities and maintaining or improving living standards; and *Cluster C:* Environmental management, which comprised decisions that allow farmers to adopt longer-term planning horizons to sustain ecosystem services, preserve biodiversity, and enhance soil health.

3.2. Farmer decision space: the mind map

This section presents the results of the mind map regarding the findings of the literature review and the case study. Figure 3 illustrates the holistic understanding that maize, beans, and coffee farmers have of their system, and how they make decisions within it. The mind map enumerates every decision (e.g., A.1. What crop can I plant?), the timing of the decision (long before the planting season begins) and associates it with the main factors related to decision-making. These factors are influenced by both climatic (shaded boxes) and non-climatic variables (on a line). The shaded boxes present factors that are influenced by climatic variables (e.g., water availability, food security, and land slope). Due to their dependency on climate variables, these factors are relevant for the development of climate services in the CA4 region. A detailed explanation of the mind map can be found in the subsequent sections.

TABLE 4 Key decisions made by maize, bean, and coffee farmers found in the literature review.

DT	maize/bean decisions	DT	coffee decisions	
(T)	A.1—Crop choice	(S)	A.1—Crop choice	CLUSTER A
(T)	A.2—Variety Choice	(S)	A.2—Variety choice	
(O)	A.3—Planting date	(T)	A.3—Replanting	
(O)	A.4—Land preparation	(O)	A.5—Pruning	
(O)	A.6—Harvesting date	(S)	B.2—Diversification	CLUSTER B
(T)	B.1—Postharvest	(O)	B.3—Labor mobility	
(T)	B.2—Diversification	(S)	B.4—Migration	
(S)	B.4—Migration	(S)	C.1—Ecosystem approach	CLUSTER C
(S)	C.1—Ecosystem approach	(T)	C.3—Soil conservation	
(T)	C.2—Quesungual system			

DT, decision type; O, operational (short-term) decision; T, tactical (medium-term) decision; S, strategic (medium-/long-term) decision.

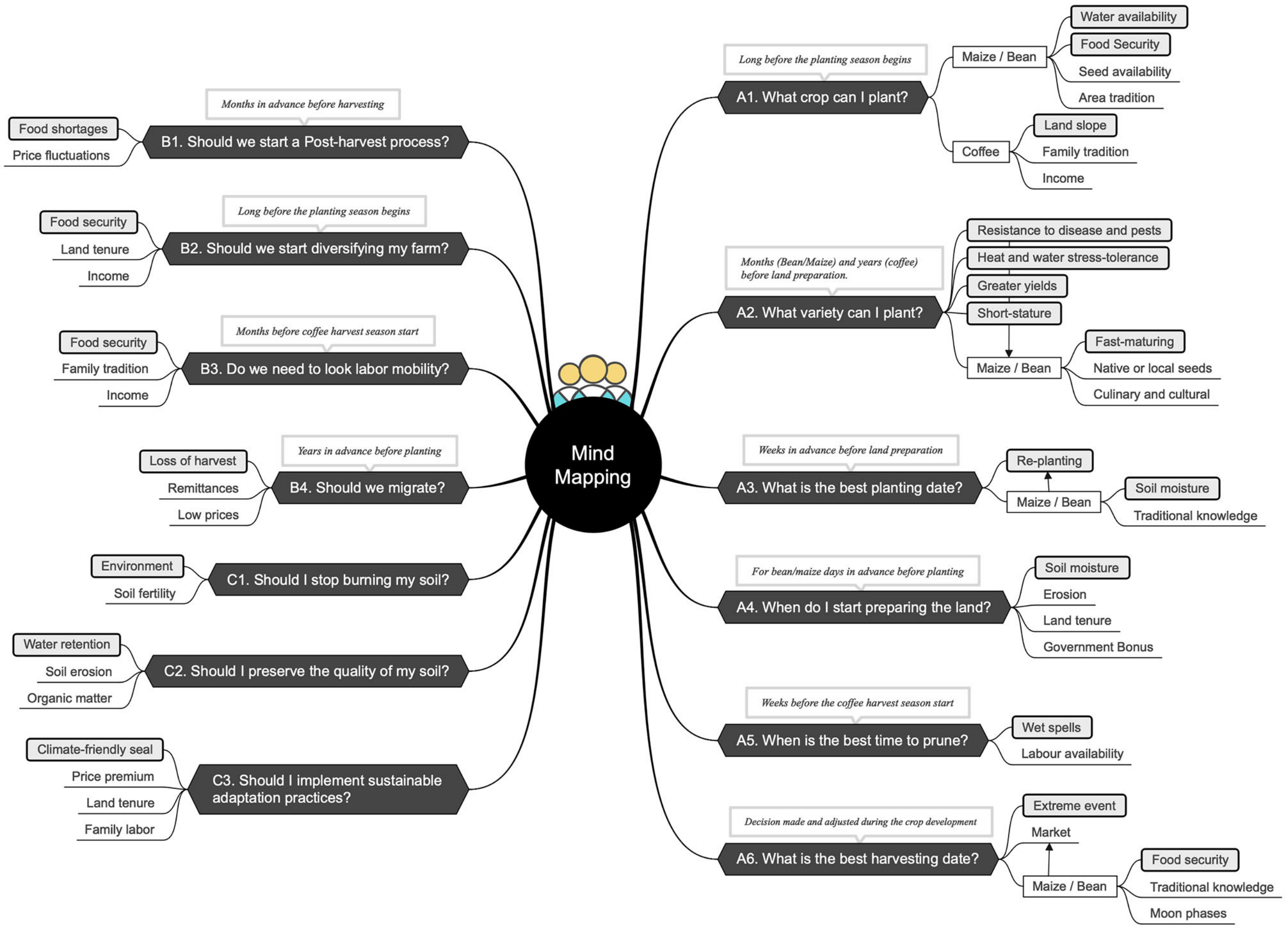

FIGURE 3
Farmer decision-making mind map to inform climate services in Central America as a result of a systematic review and the case study. The figure includes the timing of the decision in the context of Section 3.1.

3.2.1. Cluster A: production system

The findings reveal that farmers' decisions to plant maize or beans are influenced by household demands related to food security and seed availability (Mendoza et al., 2017). Farmers association FFGFA02 stated the following: "*Planting staple crops allows us to obtain the government bonus, which provides seeds*". However, need for an income has pushed farmers to start planting coffee. The shift between maize and another crop (e.g., beans, sorghum) is triggered

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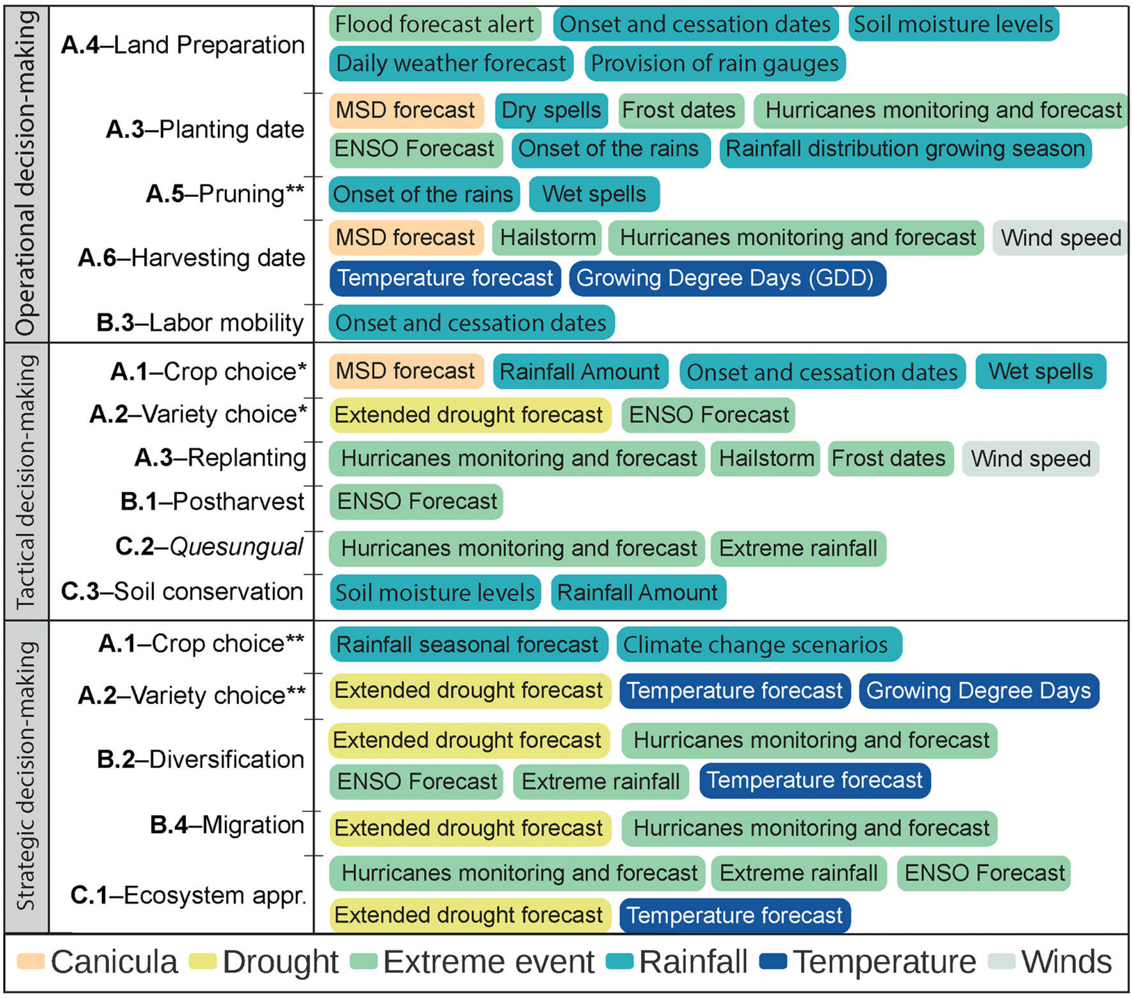

FIGURE 4
Farmer decision-making (operational, tactical and strategic) influenced by weather and climate information. The decisions (*) for maize and bean, and (**) for Coffee. The decision without asterisks involves both production systems. See Supplementary Table S3 for descriptions of each climate information source.

by the late arrival of the rains (Eakin, 2000). The slope of their land is why they decide to plant coffee over annual grain crops (FOCoffee01). For staple crops, in some cases, the preference for seed selection is due to culinary, tradition and cultural importance, and access to community-based grain banks (FFGWA01). For example, native or local varieties to make *tortillas*, *tamales*, and *atole* (a maize drink), are often consumed in almost every meal (van Etten, 2006; Hellin et al., 2017). The trigger events that lead to choosing short-stature and fast-maturing maize varieties are crop lodging from high winds and drought risk from an extended mid-summer drought (Eakin, 2000). In the case study, coffee farmers FCoffe01–03 cited resistance to disease and pests (coffee rust), heat and water stress tolerance, and higher yields are the primary reasons for selecting suitable varieties. Additionally, the use of low stature coffee varieties allows for higher spacing and facilitates pruning (Eakin et al., 2006).

This study emphasizes the importance of planting date selection as the most critical operational decision. Despite its significance, there is limited evidence regarding the utilization of weather and climate information to inform this decision-making process in Central America (Imbach et al., 2017). In the case study, the farmers (FBean01 and FMaize02) mentioned that some peers traditionally sow on the same date for the *Primera* season *–Día de la Cruz 3rd May–* waiting for the rains to begin. The first rains that fall early or mid-May trigger farmers to decide to plant. However, farmers risk planting and poor germination due to a false start to the rainy season; they have to replant with differences in height and maturity, creating problems at harvest time (Baumann et al., 2020). Farmers also consider alternative crops if an extreme event destroys their first planting at a date that prevents replanting with maize (Eakin, 2000). For coffee, a shade-grown coffee plantation lasts ∼30 years, but on a sun-grown plantation with intensive production would have to be renewed more frequently (Bunn et al., 2015). Replacing susceptible varieties with resistant varieties will trigger the renewal decision for coffee. For example, field officer FOCoffee02 stated the following: *"After the impact of rust in the 2011/12 season, coffee production recovered through the renovation* *of production areas with improved varieties that were tolerant to rust."*

During case study data collection, it was observed that some small-scale farmers in Honduras prepare the land and sow on the same day, predominantly using herbicides and machetes for weed clearance (Eash et al., 2019). The soil moisture levels that accompanies the first rainfall triggers farmers to make the decision to prepare their land; moreover, the timing of input management also depends on the rainfall and temperatures. In addition, farmers alter the landscape by creating terraces and furrows to take advantage of rainfall run-off in areas where erosion is high, or flooding is frequent (Eakin, 2000). However, land tenure affects how farmers manage their plots influencing their willingness to invest in sustainable land management practices (Mendoza et al., 2017). In the focus group, the farmers association (FFGFA02) mentioned have access to inputs at a reasonable price through rural banks—*cajas rurales*—or waiting to receive a bonus from the government to avoid the risk of losing crops. Furthermore, bean farmer FBean01 stated the following: "*preparing organic fertilizers is cheaper but takes time, and we need training on how to prepare them*."

Coffee pruning is an operational decision made once a few weeks before the beginning of the coffee harvest season and after it ends (Cerda et al., 2020). In the focus group, the coffee association FFGCA01 mentioned that the rainy seasons trigger them to decide to prune regularly to increase yields, ensure free entry of light, and rejuvenate the coffee plants. However, in times of crisis, households reduce the time and money that they dedicate for coffee maintenance practices such as weeding, pruning, and fertilization (Eakin et al., 2006). Finally, a successful staple harvest is essential for food availability in the family and selling the remainder in local markets (Baumann et al., 2020). A forecast of a prolonged mid-summer drought or an extreme event (e.g., hailstorm or hurricane) can affect the harvest of a crop, ending in total loss if the farmer does not make the correct decision of when to harvest. Mendoza et al. (2017) reported that maize growers base their harvest dates on key calendar dates (e.g., after All Saints' Day, celebrated on November 1st) or moon phases, with a full moon considered to result in much tougher grain. Coffee farmers FCoffe02–03 stated the following: "*If there is rain, the coffee ripens quickly, but when it is heavy rain and excessive sun the next day, then the coffee suffers and burns, and we have ripe but black coffee berries*."

3.2.2. Cluster B: households strategies

We found that weather and other factors heavily influence post-harvest decisions for basic grains. Upon harvest, households must evaluate grain availability and decide whether to store it for later marketing or consumption, or to consume and sell their entire harvest. Extreme events that affect crop productivity can cause food shortages and hunger spells (Alpízar et al., 2020), and preclude farmers from storing grain. In northern Nicaragua, a majority of farmers buy a portion of their grains in the market (Bacon et al., 2014). In the case study, bean and maize officers (FOBean01 and FOMaize02) mentioned that the price fluctuates due to extreme weather and climate events and that this, among other factors, triggers decisions to store the grains. Farmers mentioned that they have space on their farms with patios to dry the grains in the sun for storage (for 4 months or more) in silos (Bokusheva et al., 2012). These stored grains are used mainly during periods of high prices or food shortages in the community.

In this study, on-farm diversification is considered a strategic decision made by households to adapt to climate variability and change. In the literature review, it has been identified as a factor in managing food security risks, with diversified livelihoods generally being more food secure (Gerlicz et al., 2019; Hellin et al., 2019; Dodd et al., 2020). In the case study, the respondents mentioned home gardens, fruit trees, coffee agroforestry systems and timber as enterprises that can improve household income and food security and buffer environmental effects—high or low temperatures, strong winds, and heavy rains. However, in some cases farmers are unwilling to engage in crop diversification due to problems associated with new pests and diseases and knowledge gaps in understanding which crops it would be best to diversify associated with growing coffee (Bielecki and Wingenbach, 2019).

The findings of this study reveal that families complement and finance farm production with family members finding employment in temporary or seasonal labor (i.e., collection and processing during harvest season), generating strong mobility within and between the CA4 countries. The cash obtained during the coffee harvest is used to (i) meet the food needs of households, mainly during the food shortage season due to extreme events; and (ii) the purchase of inputs for planting staple crops in future seasons (Bacon et al., 2014). But migration can also be permanent, triggered by loss of harvest, bad prices for farmers and permanent deterioration in the standard of living of the staple grains and coffee families. The households with permanent migrants are more vulnerable to food insecurity due to the reduced family labor available, such as for replanting crops or rebuilding farm infrastructure following extreme events (Tucker et al., 2010; Ibáñez et al., 2022). However, remittances from migrants could offset these negative impacts of reduced family labor (Davis and Lopez-Carr, 2014; Alpízar et al., 2020). According to the U.S. Census Bureau 2019 the contribution of Immigrants to the United States from the CA4 Countries are: El Salvador (37%), Guatemala (29%), Honduras (19%), and Nicaragua (7%).

3.2.3. Cluster C: environmental management

In Central America, linkages exist between extreme weather events, climate change, and land-cover change. In the focus groups, the coffee association FFGCA01 mentioned shift from coffee to sugarcane due to market and climatic stressors, along with migration—partially propelled by the coffee crisis—that impacts alternative crop viability and land use in coffee-growing areas. Furthermore, financial incentives encourage reforestation of marginal agricultural land and safeguarding of forested areas against conversion into farmland (Tucker et al., 2010). The shift in farming practices in Central America is evident as the region transitions from predominantly cultivating annual crops to prioritizing planted trees, with cereals playing a subsidiary role (Gerlicz et al., 2019; Alpízar et al., 2020). This shift not only addresses land use challenges but also bolsters the resilience of farming households when faced with extreme weather events (Harvey et al., 2018).

Converting slash and burn into slash and mulch called the *Quesungual*—agroforestry system is gaining importance in Central America to increase soil fertility (Schnetzer, 2018). In the case study, the women association (FFGWA01) mentioned having environment conservation objectives in mind when deciding to stop burning residues. On moderate to steep slopes, contour and terrace planting of coffee is necessary, as they are practical measures that limit soil surface erosion, water retention capacity and loss of organic matter (Harvey et al., 2017). In the case study, the field officers (FOCoffee01–02) mentioned that farmers who experienced severe rainfall or hurricane impacts started establishing soil conservation techniques.

In recent years, the "climate-friendly" certification is gaining recognition in the coffee sector, offering a price premium to farmers who implement favorable climate adaptation and mitigation practices based on ecosystem services' conservation, restoration and sustainable management (Eakin et al., 2014). Ecosystem-based adaptation (EbA) is also a way to enhance farm management with environmental outcomes. EbA includes planting live fences, creating barriers to animal movement, and providing animal fodder, firewood, timber and fruits (Harvey et al., 2017). Many other farm-level practices have external benefits when implemented at the landscape scale, such as helping retain moisture and regulate the temperature of the soil. However, improved management with environmental outcomes in mind can be limited by (i) the lack of formal property rights that precludes farmers from longer-term planning and from making more ambitious investments in their lands; and (ii) lack of family labor due to out-migration as a barrier to implement new practices (Kearney et al., 2019; Alpízar et al., 2020).

3.3. Needs and demands of climate information

Farmer engagement in the early stages of the development of climate services can help identify variables or meteorological events of interest. It can also help determine lead times of information, formats and translation tools, and capacity gaps to enable use. Figure 4 shows the weather and climate information needs, along with the required variables (in colors), identified in the literature review and the case study for each type of farmer's decision. These decisions are categorized base on the timescale that influences them (for further details, see Supplementary Table S3). Operational and tactical decisions are made based on known or predicted conditions, and strategic decisions are based on plausible conditions or scenarios. The graph shows that extreme events and rainfall data appear to be the most required information that could support the farmers' decisions across different time scales in Central America. However, variation exists between types of decisions in terms of what information is most useful.

- **Operational decisions** impacting farmers' day-to-day fieldwork are based on local knowledge (bioindicators, observation), recent past weather conditions (e.g., days to week), current weather, short-term forecasts (3–5 days), and/or sub-seasonal (2–4 weeks) forecasts. Short-term information and early warning systems allow relatively rapid feedback and learning (Griggs et al., 2021). The production cycle of staple grains and coffee highly depends on rainfall patterns. For example, when the rains will start informs when land preparation should commence. Additionally, germination and flowering are triggered by the first rains of the rainy season. However, in the case study, the farmers mentioned that shorter *Primera* season (first rains) and extended mid-summer droughts in recent years are precluding the sowing of maize, in favor of beans. Thus, the mid-summer drought, which coincides with the maize flowering and grain-filling phases poses significantly limits small-scale farmers in CA4 countries (Baumann et al., 2020). By contrast, in the *Postrera* season (second rains), farmers are affected by excess rain and the hurricane season. Strong winds lead to lodging and grains falling, and torrential rainfall in the Eta and Iota hurricanes in 2020, for instance, brought caused substantial damage to coffee plantations, and "*milpas*" (intercropping of maize and bean) were lost entirely due to landslides (Pons et al., 2021).
- **Tactical decisions** support planning actions that depend upon farmer perceptions of the past season, climatological information, seasonal forecasts (3–6 months) and interannual variability (i.e., El Niño, La Niña, and neutral conditions) to minimize food insecurity risk and maximize annual farm profits. Tactical planning involves decisions such as crop and variety choice for staple systems, postharvest, soil conservation, diversification, and implementation of agroforestry systems that impact different stages of production. For these, farmers need access to historical climate information, seasonal rainfall, and drought forecasts. Agroforestry systems and soil conservation strategies play a crucial role in mitigating the effects of droughts. These tactical decisions, well-adapted to the region's dry and hilly conditions, are renowned for their resilience to climate change, as they help conserve water, maintain soil health, and support biodiversity.
- **Strategic decisions** require advance planning based on medium- to long-term information (interannual up to 10 years and multiple decades). For example, a 3-year drought (2014–2016) in the dry Pacific region of Central America resulted in 1.6 million people becoming food insecure and 3.5 million requiring humanitarian assistance (FAO, 2016). In the case study was difficult for the extension officers and farmers to anticipate responses due to complexity of long-term planning, and to the uncertainty of any available climate information at those timescales. However, long-term climate scenarios have been shown useful to determine suitable cropping zones (Bunn et al., 2015). Strategic planning is especially useful for coffee, which is a perennial crop. Varietal choices, diversification, full exposition or agroforestry, and migration are some of the decisions that can use mid- to long-term climate projections. The most useful information at this timescale includes historical climate data to identify any existing trends (climate change) or lack thereof, as well as to examine the current frequency of events (e.g., droughts)

over extended periods, projections of drought frequency and intensity, rainfall and temperature, and changes in the frequency of ENSO and extreme events.

4. Discussion

Climate Services can be a powerful way to better integrate local knowledge and scientific information into the decision-making process in Central America. According to Born et al. (2021), "*as complex as farmer decision-making for climate risk management might be, understanding the farmer decision space allows for identifying potentially useful information and gaps in information provision*". This paper used a mind map approach to gain a deeper understanding of how farmers make decisions within their farm systems in the CA4 region at various timescales, as a holistic system. It identifies the factors that influence these decisions at the farmer level and discusses the approach's limitations and opportunities. This analysis carries significant implications for the development of climate services in Central America. The results reveal that (i) the mind map approach facilitated and provided a holistic understanding of the farmer's decision-making. The approach was flexible enough to involve literature review and field data in the various stages of the development, whereby farmer decision-making processes can be presented in a mind map diagram, which is more understandable for the non-modelers and, thus, enhances farmer's discussion, (ii) 13 critical decisions were identified that farmers make in their crop cycle and their triggers, allowing to group them into three clusters (production, household and environmental) and classify the decisions into lead-time categories (operational, tactical and strategic) and (iii) explored the role of the weather and climate information in the maize, bean and coffee production systems involving a sequence of interrelated decisions at multiple timescales, where one of the most important factors that trigger the decisions of farmers is the food security shortages due to extreme events in Central America.

The findings highlight distinct considerations in comparison to more extensively studied regions, particularly Africa. Evidence from Africa reveals that climate services for agriculture have brought about significant changes in how farmers access and utilize climate information, influencing decision-making (Guido et al., 2020; Born et al., 2021). These studies emphasize the importance of integrating short-term actions with long-term resilience-building efforts. In Central America, marked differences in farming systems, decision-making processes, socioeconomic contexts, trade agreements, and non-climatic constraints compared to Africa play a pivotal role. These disparities underscore specific challenges that shape farmers' decisions and strategies in the region. Historical factors like land tenure disputes and civil conflicts influence decision-making. Additionally, access to credit and financial services through rural banks plays a crucial role, further highlighting the unique challenges faced in this region.

The mind map approach encouraged dialogue between farmers and agriculture experts in a two-way communication helping set opportunities and gaps in the early design of climate services. Farmers have developed strategies to decide what, when, and where to plant. The results suggest that many farmers in CA4 base the decisions of their future expectations of climate on their traditional knowledge, religious dates, and memories of near past seasons' rainfall. However, in light of this study, climate services must increase the understanding of the usefulness of weather and climate information. For example, short-term information is helpful for operational decisions that are continually adjusted in the next few days (i.e., apply inputs, land preparation and management). On the contrary, a rainfall forecast for the next few days would be inadequate to decide on a crop or variety for planting. However, the weather forecast may be adequate to determine the planting window, whereas a climate forecast for the entire season appears not to be (Guido et al., 2020). This study facilitated an understanding of the usefulness of specific weather and climate information, as well as the potential applications for operational, tactical, and strategic farmer decisions.

This paper makes several contributions to the design and implementation of climate services in Central America for small-scale farmers in staple and coffee systems. First, the climate services developers must recognize that many coffee and basic grain small-scale farmers already actively demand tailored weather and climate information without leaving aside their existing experience and local knowledge. Second, the fact that farmer's decision-making complexity varies across systems and landscapes represents a significant opportunity to design cross-time scale climate services. Third, the results also indicate the need to enhance climate literacy among farmers, enabling them to better incorporate and demand relevant information. This improvement will empower farmers to determine which tools and knowledge are most valuable for their specific situations.

4.1. Limitations and future research and action

With the development of the mind map it was possible to identify gaps and provide recommendations for providing climate services in Central America based on evidence from the literature review and a range of qualitative data (i.e., interviews, focus groups and observation). However, this research does not address how farmers can access weather and climate information to support their decision-making. This implies that farmers may be utilizing data from various sources that this study was unable to account for. This paper acknowledges that the impacts of using climate and weather information cannot be isolated from other variables, such as price fluctuations, migration caravans, or government incentives. Despite the study's novelty, only a semi-structured interviews and focus groups with a small sample in Honduras were conducted with a relatively small number of participants as a case study. Future studies could involve a larger sample of farmers and extension officers from various staple and coffee zones in Central America to gain deeper insights into the usability of climate and weather information services for on-the-ground decision-making. Additionally, research is needed on gender, youth, and social inclusion in climate services considering the roles of different household members in decision-making and differing access to information.

The mind map was the first non-formal representation of ontologies applied in Central America to better understand farmer decision-making that could evolve into a more formal Ontology Web Language, establishing a decision support system to help the process of co-production into the climate services development. However, as technologies emerge, it is important to consider the integration of traditional knowledge with new sources of information (e.g., advice from extension officers, seasonal forecasts, early warning systems, and agroclimatic calendars) to foster innovation for decision-making. This study could help the farmers adjust their decision-making to operate time-efficiently and avoid extreme climatic events during sensitive growing phases. However, more efforts should be made to improve farmers' capacity and skills toward using weather/climate information in farm management decisions, ensuring agricultural cropping systems' future adaptability and profitability.

5. Conclusion

By examining the farmer decision-making mind map within their system, understanding the factors that trigger those decisions, and identifying the weather and climate information required, along with the challenges faced by small-scale farmers in Central America, regional governments, in collaboration with donors, researchers, and the private sector, can effectively support small agricultural producers in implementing climate change adaptation measures. For this, small-scale farmers require tailored climate services with technical assistance and financial and legislative support to implement the appropriate adaptation measures for their production systems and their local context.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Research Ethics Committee, University of Reading. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DG: conceptualization, methodology, formal analysis, writing—original draft, writing—review and editing. GC, PD, DO, and JR-V: Writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2023.1235601/full#supplementary-material

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