Supplementary Material

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

Diana Giraldo1,2,\*, Graham Clarkson1, Peter Dorward1, Diego Obando3, Julian Ramirez-Villegas4,5

1 University of Reading, School of Agriculture, Policy and Development, United Kingdom.

2 International Center for Tropical Agriculture (CIAT), Cali, Colombia.

3 International Center for Tropical Agriculture (CIAT), Tegucigalpa, Honduras.

4 International Center for Tropical Agriculture (CIAT), c/o Bioversity International, Rome, Italy

5 Plant Production Systems Group, Wageningen University & Research, Wageningen, The Netherlands

\* Corresponding author E-mail: [d.c.giraldo@pgr.reading.ac.uk](mailto:d.c.giraldo@pgr.reading.ac.uk)

A combination of the following search strings was used to search for current place-based literature on farmer decision-making in Central America, using Google Scholar (GS) and Web of Science (WoS) search criteria:

1. TS= (“decision mak\*” OR "farmer\*" AND "Central America" AND “maize” OR “bean”)
2. TS= (“decision mak\*” OR "farmer\*" AND "Central America" AND “coffee”)
3. AB= (El Salvador OR Guatemala OR Honduras OR Nicaragua OR “climat\*”)
4. Year Published = 2000-2020
5. Language= ‘English’ or ‘Spanish’

Supplementary Table S1. Criteria for inclusion of searched articles into the literature review.

|  |
| --- |
| Information collected for included articles |
| The study shows pieces of evidence on decision-making by the farmer (on the ground) |
| The study includes in its methodology the collection of primary data in the field with farmers through surveys, interviews, and case studies. |
| The study includes in its methodology participatory action research approaches (e.g., focus group, mapping, workshops) |

Supplementary Table S2. References list that addresses each farmer decision making in Guatemala (36%) Honduras (29%), El Salvador (18%), and Nicaragua (18%).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **#** | **Authors (year)** | **Country(ies)** | **Keywords** | **Unit of analysis** |
| Maize and Bean production systems | | | | |
| 01 | Alpízar *et al.* (2020) | Guatemala Honduras | Extreme events Food insecurity Food shortages | 439 households surveyed |
| 02 | Baumann *et al.* (2020) | Nicaragua | Seed management  Climate adaptation strategies | 800 smallholder farmers |
| 03 | Bokusheva *et al.* (2012) | Guatemala Honduras El Salvador Nicaragua | Postharvest Food security Metal silos | 1535 households surveyed |
| 04 | Chain-G. *et al.* (2018) | Guatemala Honduras | Ecosystem services Reforestation | 160 households |
| 05 | Dodd *et al.* (2020) | Honduras | Migration Food insecurity | 248 households |
| 06 | Eash *et al.* (2019) | Guatemala Honduras El Salvador | Planting date Land preparation Climate adaptation strategies | Interviews and six field trials |
| 07,08 | Hellin *et al.* (2017 & 2018) | Guatemala | Maize diversity Poverty reduction Buena Milpa | 989 households surveyed |
| 09,10 | Hellin *et al.* (2019); Hellin & Schrader (2003) | Honduras El Salvador Nicaragua | Ecosystem-based Adaptation  Direct incentives | 500 smallholder farmers |
| 11 | Kearney *et al.* (2019) | El Salvador | Ecosystem services Quesungual system | 25 on-farm trials |
| 12 | Mendoza *et al.* (2017) | Guatemala | Postharvest Land Tenure Harvest date | 280 households surveyed |
| 13 | Morris *et al.* (2013) | El Salvador | Inputs management Milpa | 29 farmers |
| 14,15 | Olson *et al.* (2012); van Etten (2006) | Guatemala El Salvador | Variety choice Inputs management Biodiversity | 29 households &  40 farmers |
| 16 | Sain *et al.* (2017) | Guatemala | CSA\* practices Ecosystem-based Adaptation | 42 CSA stakeholders |
| 17 | Schmidt *et al.* (2012) | Guatemala Honduras El Salvador Nicaragua | Climate adaptation strategies  Climate change | 480 farmers & Field trials |
| 18 | Viguera *et al.* (2019) | Guatemala | Extreme events  Ecosystem-based Adaptation | 264 farmers surveyed |
| 19 | Wyckhuys & O’Neil (2007) | Honduras | Pest management Biological control | 30 farmers |

\*Climate Smart Agriculture (CSA)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **#** | **Authors (year)** | **Country (ies)** | **Keywords** | **Unit of analysis** |
| Coffee production system: | | | | |
| 01 | Bacon *et al.* (2014) | Nicaragua | Seasonal hunger Trade cooperatives | 244 households surveyed |
| 02 | Bielecki & Wingenbach (2019) | Guatemala | Diversification Leaf rust outbreak | 10 farmers case studies |
| 03 | Discua Cruz *et al.* (2020) | Guatemala Honduras Nicaragua | Specialty Coffee | 3 case studies |
| 04, 05 | Eakin *et al.* (2006 & 2014) | Guatemala Honduras | Extreme events Organic coffee Postharvest | 65 and 560 households surveyed |
| 06 | Gerlicz *et al.* (2019) | Guatemala | Diversification Farmer typologies | 15 smallholder farmers |
| 07,08 | Harvey *et al.* (2017 & 2018) | Guatemala Honduras | Ecosystem services Coffee & Maize system | 300 smallholders,  860 smallholders |
| 09 | Méndez *et al.* (2017) | El Salvador Nicaragua | Organic certification Diversification | 2 case studies |
| 10 | Quiroga *et al.* (2015) | Nicaragua | Water management | 212 farmers |
| 11 | Tucker *et al.* (2010) | Guatemala Honduras | Extreme events Migration | 65 household survey |
| 12 | Ward *et al.* (2017) | Honduras | Coffee leaf rust Choice Variety Organic certification | 20 farmers interviewed |

|  |  |
| --- | --- |
| 1. **Coffee word cloud** | 1. **Maize and beans word cloud** |
| **Text, letter  Description automatically generated** | **Text, letter  Description automatically generated** |

**Supplementary Figure S1.** Word clouds of vocabulary used in the (a) Coffee and (b) Maize and beans literature review in Central America.

Data collection Instruments – Case study protocol

Template for Taking Notes from Interviews and Focus Groups: Extension Officers/Farmer Case Study.

|  |  |  |
| --- | --- | --- |
| **1** | **Crop** | 1. Coffee b) Maize/Bean |
| **2** | **Method** | 1. Individual interview b) Focus Groups |
| **3** | **Place** |  |
| **4** | **ID** |  |
| **5** | **Date** |  |
| **6** | **Gender of respondent** |  |
| **7** | **Age of respondent** |  |

1. **When and why did you start planting coffee, maize and/or bean?**

*Notes: Is the farm where you plant your property or rented? What area is planted?*

1. **When (and in which seasons) do you plant coffee, maize, and/or beans?**

*Notes: Ask the officers about producing regions and farmers' typology.*

1. **How have you been doing with your coffee, maize and/or bean planting and harvesting?**

*Notes: Consumption, income, market, seeds*

1. **Crop seasonal calendar and decisions.**

*Note: The goal is to comprehend the key decisions that farmers make regarding coffee, maize, and/or beans, the timing of these decisions, and how they are influenced by weather and climate conditions (using a Seasonal Calendar).*

* You will need a flip chart and pens to draw the Seasonal Calendar. Alternatively, it can be drawn on the ground using leaves, stones or other objects.
* Discuss the purpose of drawing the Seasonal Calendar with the farmers (give an example – Manual PICSA Dorward *et al.,* 201)

**Text, whiteboard

Description automatically generated**

Figure 3. Agroclimatic calendar with coffee farmers in Intibucá - Honduras. (Photo by the lead author, August 2021)

***Procedure with the farmers: On your flip chart draw your example Seasonal Calendar***

1. Draw a line at the top of the flipchart to show time and mark smaller time periods that the participants are familiar with (e.g., local names for months or parts of seasons) on it. Make sure that there are enough time periods to cover the whole crop cycle.
2. Draw rows on the left margin of the flipchart (as shown in the example); enough rows for all of the main crops grown on the farm. Put one crop on each row.
3. Then, for each crop, draw a line from when the first decision for that crop happens (e.g., land preparation) to when the last decision for the crop happens (e.g., harvesting).
4. Underneath the crop line, define when each main decision (e.g., planting, weeding...) is done with a decision line and a symbol.
5. On top of the crop line, indicate whether and how these decisions may be affected by the weather and/or climate.

***Procedure with the field officers:***

You may wish to prepare the example in advance and then talk the field officers through the process (see examples below prepare for the researcher based on the literature review and fields experiences). If the calendar is going to be used to look at the details of crop management, you should give each crop more space, by putting each decision on a separate row or draw a separate calendar for each crop.

|  |  |  |
| --- | --- | --- |
| **Month/ Climate** | **Farm decisions** | **Who does the activity?** |
| **January** |  |  |
| **February** |  |  |
| **March** |  |  |
| **April** |  |  |
| **May** |  |  |
| **Jun** |  |  |
| **July** |  |  |
| **August** |  |  |
| **September** |  |  |
| **October** |  |  |
| **November** |  |  |
| **December** |  |  |

After farmers and field officers have created their Seasonal Calendars, instruct them to identify and mark on the calendars:

1. Decisions and their timing that are particularly influenced by weather and climate. These could include significant choices like crop selection or more specific ones like planting and weeding times.
2. Specify the weather and climate elements that influence each decision.
3. Specify the weather and climate variables that they want to receive to support planning and better decision making in their productive systems.

Supplementary Table S3. Description of the weather and climate information variables as identified in the literature review and the case study, with a focus on their relevance to each type of farmer's decision.

|  |  |
| --- | --- |
| **Variable** | **Description** |
| Climate change scenarios | Includes historical climate data to identify existing trends, projections of drought, as well as changes in rainfall and temperature. It also provides information on shifts in the frequency of ENSO and extreme events. Additionally, features maps depicting the suitability of future coffee-growing areas in Central America, considering its high sensitivity to temperature. |
| Daily weather forecast | Rainfall and temperatures daily forecast helpful for operational decisions that are continually adjusted in the next few days (i.e., apply inputs, land preparation and management). |
| Dry spells | Refers to a period (number of days) of below-average rainfall or limited water availability in a particular region, leading to drought conditions and potential water shortages. Dry spells have notable impacts on coffee cultivation, including disrupted flowering and fruiting, reduced bean quality and size, heightened vulnerability to pests and diseases, uneven ripening, lower yields, water stress and defoliation, and the potential for altering the flavor profile of coffee beans due to insufficient moisture. In maize/bean, the implementation of strategies such as improved water management, drought-tolerant varieties, and soil conservation techniques can help mitigate the negative impacts of dry spells. |
| ENSO forecast | El Niño-Southern Oscillation (ENSO) monitoring and forecast provides information about the expected climate conditions in the tropical Pacific Ocean over the coming months. Monitoring the periodic warming (El Niño) and cooling (La Niña) of sea surface temperatures in the central and eastern equatorial Pacific Ocean influences everything from rainfall patterns to temperature extremes. |
| Extended drought forecast | Provides information about the potential occurrence, severity, and duration of drought conditions over an extended period, typically beyond the short-term weather forecasts. |
| Extreme rainfall forecast | Refers to unusually heavy or intense precipitation events that result in a significant amount of rainfall in a relatively short period of time. This type of rainfall can lead to various impacts, including flash floods, landslides, and other forms of water-related damage. |
| Flood Forecast alerts | These alerts are typically issued by meteorological and hydrological agencies, and they convey important details about the possibility, severity, timing, and location of flooding (e.g., flood risk level). |
| Frost dates | Involved average dates when frosts are most likely to occur. However, this can vary greatly depending on the geographical location, altitude, and local climate. Determining the estimated frost dates aids in planning the timing of planting and transplanting. |
| Growing Degree Days (GDD) | (GDD) information is crucial for understanding and predicting the growth and development of plants in relation to temperature. GDD is a measurement that quantifies the accumulation of heat over a certain threshold temperature during a specific period. |
| Hailstorm | Hailstorm alerts serve as warnings that provide information about the occurrence, severity, and potential impact in a specific area. |
| Hurricanes monitoring and forecast | Provide a comprehensive understanding of the storm's characteristics and potential impacts, enabling communities to make informed decisions and take necessary actions to mitigate risks and protect lives and crops. |
| Mid-Summer Drought (MSD) forecast | Sub-seasonal to seasonal prediction (S2S), defined “as the time range between 2 weeks and 2 months”, such as forecasts of mid-summer drought (MSD, knows as ‘canicula’). MSD is a period of reduced precipitation that typically occurs in July and August, poses a major limitation in Central America, as this period usually coincides with the flowering date and subsequent grain-filling stage of maize development. |
| Onset and cessation dates | Onset dates indicate when a region experiences the start of the rainy season. Conversely, cessation dates refer to the end of consistent rainfall after a wet period. This information aids farmers in enhancing their decision-making regarding the choice of crop types and varieties. Additionally, it has the potential to lower the risks and expenses associated with the process of re-sowing or re-planting. |
| Provision of rain gauges | Capacity building and rain gauges network within communities serves to promote the adoption of strategies that bolster climate services. This empowers farmers and extension officers to collect climate data at the grassroots level, fostering a sense of ownership and engagement. |
| Rainfall amount | The probability distribution of rainfall amounts at a specific location over a certain period can be expressed in terms of probabilities. This information is important for water resource management. |
| Rainfall distribution | The distribution could describe the likelihood of various amounts of rainfall occurring within a given period. For example, with this information, farmers can strategically plan their pesticide and fungicide purchases for pest and disease control, as well as the application of fertilizers. |
| Rainfall seasonal forecast | Also known as a Seasonal Climate Outlook, is a prediction of the expected rainfall patterns and conditions for a specific geographical area over an upcoming season. This type of forecast typically covers a time frame of several months (1-6 months). |
| Soil moisture levels | The soil moisture levels that accompanies the first rainfall triggers farmers to make the decision to prepare their land. 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. |
| Temperature forecast | Involves predicting the future temperatures in a specific location over a certain period. This can be done for short-term timeframes (daily forecasts) or for longer-term periods (weekly or monthly forecasts). |
| Wet spells | Refers to a period when a region experiences higher-than-normal levels of rainfall. This could lead to flooding, waterlogging, and other water-related issues. Wet spells can influence planting, crop growth, and harvesting. |
| Wind speed | It indicates how fast the air is moving at a given location and time. The trigger events that lead to choosing short-stature and fast-maturing maize varieties are crop lodging from high winds. |

# References

Alpízar, F., Saborío-Rodríguez, M., Martínez-Rodríguez, M.R., Viguera, B., Vignola, R., Capitán, T., Harvey, C.A., 2020. Determinants of food insecurity among smallholder farmer households in Central America: recurrent versus extreme weather-driven events. Reg. Environ. Change 20, 22. https://doi.org/10.1007/s10113-020-01592-y

Bacon, C.M., Sundstrom, W.A., Flores Gómez, M.E., Ernesto Méndez, V., Santos, R., Goldoftas, B., Dougherty, I., 2014. Explaining the ‘hungry farmer paradox’: Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua’s corn and coffee markets. Glob. Environ. Change 25, 133–149. https://doi.org/10.1016/j.gloenvcha.2014.02.005

Baumann, M.D., Zimmerer, K.S., Etten, J. van, 2020. Participatory seed projects and agroecological landscape knowledge in Central America. Int. J. Agric. Sustain. 18, 300–318. https://doi.org/10.1080/14735903.2020.1775930

Bielecki, C.D., Wingenbach, G., 2019. Using a livelihoods framework to analyze farmer identity and decision making during the Central American coffee leaf rust outbreak: implications for addressing climate change and crop diversification. Agroecol. Sustain. Food Syst. 43, 457–480. https://doi.org/10.1080/21683565.2019.1566191

Bokusheva, R., Finger, R., Fischler, M., Berlin, R., Marín, Y., Pérez, F., Paiz, F., 2012. Factors determining the adoption and impact of a postharvest storage technology. Food Secur. 4, 279–293. https://doi.org/10.1007/s12571-012-0184-1

Chain-Guadarrama, A., Martínez-Rodríguez, M.R., Cárdenas, J.M., Vílchez-Mendoza, S., Harvey, C.A., 2018. Adaptación basada en Ecosistemas en pequeñas fincas de granos básicos en Guatemala y Honduras. Agron. Mesoam. 571–583. https://doi.org/10.15517/ma.v29i3.32678

Discua Cruz, A., Centeno Caffarena, L., Vega Solano, M., 2020. Being different matters! A closer look into product differentiation in specialty coffee family farms in Central America. Cross Cult. Strateg. Manag. 27, 165–188. https://doi.org/10.1108/CCSM-01-2019-0004

Dodd, W., Gómez Cerna, M., Orellena, P., Humphries, S., Sadoine, M.L., Zombré, D., Zinszer, K., Kipp, A., Cole, D.C., 2020. Factors Associated with Seasonal Food Insecurity among Small-Scale Subsistence Farming Households in Rural Honduras. Int. J. Environ. Res. Public. Health 17, 706. https://doi.org/10.3390/ijerph17030706

Eakin, H., Tucker, C., Castellanos, E., 2006. Responding to the coffee crisis: a pilot study of farmers’ adaptations in Mexico, Guatemala and Honduras. Geogr. J. 172, 156–171.

Eakin, H., Tucker, C.M., Castellanos, E., Diaz-Porras, R., Barrera, J.F., Morales, H., 2014. Adaptation in a multi-stressor environment: perceptions and responses to climatic and economic risks by coffee growers in Mesoamerica. Environ. Dev. Sustain. 16, 123–139. https://doi.org/10.1007/s10668-013-9466-9

Eash, L., Fonte, S.J., Sonder, K., Honsdorf, N., Schmidt, A., Govaerts, B., Verhulst, N., 2019. Factors contributing to maize and bean yield gaps in Central America vary with site and agroecological conditions. J. Agric. Sci. 157, 300–317. https://doi.org/10.1017/S0021859619000571

Etten, J.V., 2006. Changes in farmers’ knowledge of maize diversity in highland Guatemala, 1927/37-2004. J. Ethnobiol. Ethnomedicine 2, 12. https://doi.org/10.1186/1746-4269-2-12

Gerlicz, A., Méndez, V.E., Conner, D., Baker, D., Christel, D., 2019. Use and perceptions of alternative economic activities among smallholder coffee farmers in Huehuetenango and El Quiché departments in Guatemala. Agroecol. Sustain. Food Syst. 43, 310–328. https://doi.org/10.1080/21683565.2018.1532480

Harvey, C.A., Martínez-Rodríguez, M.R., Cárdenas’, J.M., Avelino, J., Rapidel, B., Vignola, R., Donatti, C.I., Vilchez-Mendoza, S., 2017. The use of Bieby smallholder farmers in Central America. Agric. Ecosyst. Environ. 246, 279–290. https://doi.org/10.1016/j.agee.2017.04.018

Harvey, C.A., Saborio-Rodríguez, M., Martinez-Rodríguez, M.R., Viguera, B., Chain-Guadarrama, A., Vignola, R., Alpizar, F., 2018. Climate change impacts and adaptation among smallholder farmers in Central America. Agric. Food Secur. 7, 57. https://doi.org/10.1186/s40066-018-0209-x

Hellin, J., Cox, R., López-Ridaura, S., 2017. Maize Diversity, Market Access, and Poverty Reduction in the Western Highlands of Guatemala. Mt. Res. Dev. 37, 188–197. https://doi.org/10.1659/MRD-JOURNAL-D-16-00065.1

Hellin, J., Ratner, B.D., Meinzen-Dick, R., Lopez-Ridaura, S., 2018. Increasing social-ecological resilience within small-scale agriculture in conflict-affected Guatemala. Ecol. Soc. 23. https://doi.org/10.2307/26799129

Hellin, J., Schrader, K., 2003. The case against direct incentives and the search for alternative approaches to better land management in Central America. Agric. Ecosyst. Environ. 99, 61–81. https://doi.org/10.1016/S0167-8809(03)00149-X

Hellin, J.J., Lopez-Ridaura, S., Sonder, K., Camacho Villa, T.C., Gardeazabal Monsalue, A., 2019. A guide to scaling soil and water conservation in the Western Highlands of Guatemala. CIMMYT.

Kearney, S.P., Fonte, S.J., García, E., Siles, P., Chan, K.M.A., Smukler, S.M., 2019. Evaluating ecosystem service trade-offs and synergies from slash-and-mulch agroforestry systems in El Salvador. Ecol. Indic. 105, 264–278. https://doi.org/10.1016/j.ecolind.2017.08.032

Méndez, V.E., Caswell, M., Gliessman, S.R., Cohen, R., 2017. Integrating Agroecology and Participatory Action Research (PAR): Lessons from Central America. Sustainability 9, 705. https://doi.org/10.3390/su9050705

Mendoza, J.R., Sabillón, L., Martinez, W., Campabadal, C., Hallen-Adams, H.E., Bianchini, A., 2017. Traditional maize post-harvest management practices amongst smallholder farmers in Guatemala. J. Stored Prod. Res. 71, 14–21. https://doi.org/10.1016/j.jspr.2016.12.007

Morris, K.S., Mendez, V.E., Lovell, S.T., Olson, M., 2013. Conventional Food Plot Management in an Organic Coffee Cooperative: Explaining the Paradox. Agroecol. Sustain. Food Syst. 37, 762–787. https://doi.org/10.1080/21683565.2013.774303

Olson, M.B., Morris, K.S., Méndez, V.E., 2012. Cultivation of maize landraces by small-scale shade coffee farmers in western El Salvador. Agric. Syst. 111, 63–74. https://doi.org/10.1016/j.agsy.2012.05.005

Quiroga, S., Suárez, C., Solís, J.D., 2015. Exploring coffee farmers’ awareness about climate change and water needs: Smallholders’ perceptions of adaptive capacity. Environ. Sci. Policy 45, 53–66. https://doi.org/10.1016/j.envsci.2014.09.007

Sain, G., Loboguerrero, A.M., Corner-Dolloff, C., Lizarazo, M., Nowak, A., Martínez-Barón, D., Andrieu, N., 2017. Costs and benefits of climate-smart agriculture: The case of the Dry Corridor in Guatemala. Agric. Syst. 151, 163–173. https://doi.org/10.1016/j.agsy.2016.05.004

Schmidt, A., Eitzinger, A., Sonder, K., Sain, G., Rizo, L., Rodriguez, B., Hellin, J., Fisher, M., Läderach, P., San Vicente, F., 2012. Tortillas on the roaster (ToR): central America maize-beans systems and the changing climate.

Tucker, C.M., Eakin, H., Castellanos, E.J., 2010. Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico. Glob. Environ. Change, Adaptive Capacity to Global Change in Latin America 20, 23–32. https://doi.org/10.1016/j.gloenvcha.2009.07.006

Viguera, B., Alpizar, F., Harvey, C.A., Ruth Martinez-Rodriguez, M., Saborio-Rodriguez, M., Contreras, L., 2019. Climate change perceptions and adaptive responses of small-scale farmers in two Guatemalan landscapes. Agron. Mesoam. 30, 313–331. https://doi.org/10.15517/am.v30i2.33938

Ward, R., Gonthier, D., Nicholls, C., 2017. Ecological resilience to coffee rust: Varietal adaptations of coffee farmers in Copán, Honduras. Agroecol. Sustain. Food Syst. 41, 1081–1098. https://doi.org/10.1080/21683565.2017.1345033

Wyckhuys, K.A.G., O’Neil, R.J., 2007. Local agro-ecological knowledge and its relationship to farmers’ pest management decision making in rural Honduras. Agric. Hum. Values 24, 307–321. https://doi.org/10.1007/s10460-007-9068-y