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TECHNOLOGY ADOPTION BY CACAO FARMERS IN SAN VICENTE DE CHUCURI, SANTANDER: THE ROLE OF CADMIUM REGULATIONS

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ABSTRACT

Cadmium (Cd) is a significant public health concern. This heavy metal could cause kidney failure and cancer; hence, food safety authorities have regulated Cd content in food products, including chocolate. For thousands of rural residents, cacao, known as the chocolate tree, constitutes the main, if not the only, source of income. Therefore, Cd regulations threaten not only the principal source of income of an already vulnerable population but also their intangible cultural heritage assets. While strategies have been explored to mitigate Cd in agriculture, the current low adoption of technologies among cacao farmers in Colombia jeopardizes the effectiveness of the efforts to prevent negative consequences of the accumulation Cd in cacao beans. For this reason, understanding what factors influence adoption of agricultural practices addressing Cd accumulation in cacao becomes a priority goal of strategies making the cacao tree an engine for development.

It is currently unknown if cacao farmers are willing to adopt agricultural practices, particularly those reported as beneficial for alleviating the Cd issue, nor its known how the regulation of this heavy metal influences such adoption decisions. This Ph.D. research project aims to fill this research gap and contribute to understanding the adoption of agricultural practices intending to tackle Cd in cacao crops. This research was conducted in the municipality of San Vicente de Chucuri in Santander, Colombia. San Vicente, known as the "Cacao Capital in Colombia," is the country's primary producer of cocoa beans. Due to its privileged location, the region offers cropland suitability to more than 3,000 families dependent on cacao for their livelihood. Notwithstanding the above, the region's potential could be threatened by elevated cadmium levels in the soils.

Grounded theory was selected as the qualitative research methodology due to the lack of knowledge regarding the variables and variables relationships that intervene in the adoption of clonal cultivars and soil amendments, two critical innovations towards Cd alleviation. Two theoretical explanations, one for each innovation, were developed by following an iterative data collection and analysis process. The participants' descriptions provided the basis for developing the Soil Amendments Adoption Model (SAAM) and the Cacao Clones Adoption Model (CCAM), two models that describe the adoption of these innovations among cacao farmers from San Vicente de Chucuri. The models identify factors involved in adaptation of clonal cacao and soil amendments and provide a foundations for further research and, design and implementation of interventions using these technologies.

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CHAPTER 1

INTRODUCTION

Problem Statement

Cadmium (Cd) could cause major human health issues. Consumption of high amounts and after long exposure of this heavy metal could cause kidney failure (EFSA, 2012) and has been recognized by the International Agency for Research on Cancer as a Group 1- known human carcinogenic (IARC, 2019). An important human exposure to Cd is through plant-derived food (Clemens & Ma, 2016; H. Wu et al., 2016). Consequently, to reduce Cd intake in humans, its content in food products has been regulated by food safety authorities in several countries. In 2014, the European Union set maximum levels for Cd in chocolate products. While limits were not explicitly set to cocoa beans, the raw product used to make chocolate, buyers are placing restrictions to guarantee the final product (chocolate) falls below the maximum permissible level (Meter et al., 2019). Currently, limits on Cd levels in chocolate have been set in countries like the USA (California), Australia, Argentina, New Zealand, and Russia (Jiménez, 2015; Meter et al., 2019).

Small cocoa farmers from Latin America and the Caribbean (LAC) countries are the most affected by Cd regulations in chocolate. The cocoa tree, also called the cacao tree, is grown by small-scale producers who constitute the backbone of cocoa production in LAC (Ríos et al., 2017). Besides the production-related challenges small farmers face, cocoa producers in LAC now must deal with a new issue: Cd. In a recent review of research and potential mitigation solutions to Cd in cocoa, Meter et al. (2019) compiled 21 references reporting Cd contents in cocoa of African, Asian, and LAC countries. Their findings suggest that LAC is the region with higher heavy metal contents; based on the Cd levels in cocoa beans, the authors indicate that the new regulations will affect cocoa producers in the region, including Colombia. Although the previous authors did not include data for Colombia in their compilation, high Cd concentrations in soils (Bravo & Benavides-Erazo, 2020), in leaves and beans (Rodríguez Albarrcín et al., 2019), and Colombian chocolate (Echeverry & Reyes, 2016) have been reported.

The literature suggests experimental and science-based approaches towards alleviating Cd in cocoa trees. However, we do not know if farmers are able and willing to implement the investigated approaches. The same is true for ongoing research projects, which have focused on soil and nutrient management and cacao genetics' role in Cd uptake, leaving the socio-economic component aside (Meter et al., 2019). While technical solutions have been proposed, currently, no information supports the adoption of such practices by cocoa farmers in Colombia, a country with one of the lowest cacao productivity worldwide (FAOStat, 2020). It has been reported that a major reason for the low productivity is the low technology adoption rates among farmers (Castellanos et al., 2007; Palencia, 2017). Adequate plant nutrition and adoption of new varieties, critical practices towards Cd alleviation, are among those technologies that some farmers seldom implement. Consequently, the low level of technology adoption could jeopardize the effectiveness of the interventions that would enable the cocoa sector to overcome the Cd issue in Colombia; hence increasing our understanding of the barriers and opportunities of the adoption process is critical.

Studying the Adoption of Technology in Agriculture

Understanding technology adoption by actors along supply chains is critical as addressing major societal challenges requires new practices and products to be put into practice. Hereafter, all these practices (i.e., applying fertilizers, etc.) and these products (i.e., improved varieties, etc.) will be referred to as innovations. Research on the adoption of innovations recognizes adopting decision-making as a process with multiple stages rather than an event (Pannell & Zilberman, 2020). Weersink & Fulton (2020) assume six stages in the adoption process: awareness, non-trial evaluation, trial evaluation, adoption, revision, and dis-adoption. Similarly, Rogers' (2003) diffusion theory proposes an innovation-decision approach through which an individual passes from understanding how an innovation functions, forming a favorable attitude towards the innovation, making a decision to adopt it, implementing it, and finally confirming the previous decision.

Innovations' characteristics, as well as the social systems through which they are communicated, are two main elements that affect the diffusion of innovations (Rogers, 2003). In the latter, farmers' characteristics and their social contexts have been proposed as predictors of the adoption of agricultural innovations. In Niger, for instance, Ousmane & Nafiou (2019) found that age and education level of the household head, farm size, and household income and wealth determined the adoption decisions made by farmers. The attributes of innovations also explain their adoption rate. According to Rogers (2003), the five different characteristics determining the adoption of innovations are: relative advantage, compatibility, complexity, trialability, and observability. Adopters' perceptions of these attributes and their influence on adoption behavior have been extensively studied. For example, Kapoor et al. (2014) conducted a meta-analysis using 226 articles that used Roger's innovations attributes to explain adoption decisions.

Social scientists also rely on additional models to identify the factors influencing adoption behaviors. Among those models, Ajzen's (1991) Theory of Planned Behavior (TPB) and Davis's (1986) Technology Acceptance Model (TAM) stand out as frameworks frequently used to better explain farmers' decision-making. As an illustration, Flett et al. (2004) used the TAM to elucidate the adoption of four dairy farming technologies in New Zealand, a worldwide player of the dairy industry. Similarly, in Iran, Sharifzadeh et al. (2017) used the TAM to measure rice farmers' acceptance and use of biological control strategies. Meanwhile, the TPB has been utilized in China to reveal the causal chain among farmers' perceptions, behavioral responses, and the consequential results of such actions (Liu & Luo, 2018), and in Australia to create a predictive model of pro-environmental agricultural practices (Price & Leviston, 2014).

Study Rationale

Models on the adoption of innovations provide researchers a structured way to approach the adoption process and to elucidate the factors influencing this phenomenon. However, a recent proliferation of adoption models has resulted in the absence of agreement when explaining adoption behaviors. This situation is problematic for decision-takers who rely on a body of literature that is often unable to provide guidance on the variables that can be revised to design efficient interventions (Montes de Oca Munguia et al., 2021; Montes de Oca & Llewellyn, 2020). Under those circumstances, Montes de Oca Munguia et al. (2021) suggest that researchers should question whether the same adoption process can represent the adoption of all innovations. This question is very much relevant to this research. As for the cocoa sector, the social system and the innovations' characteristics differ from other crops for which there is more information (Duque, 2018).

Most of the cocoa worldwide, including Colombia, is produced by small farmers (Abbott et al., 2018; Baquero, 2018). When is come to adoption decisions, small farm holders might be more influenced by cultural norms and prioritize subsistence over profits (Llewellyn & Brown, 2020). Access to factors of production is also problematic among cocoa farmers. In San Vicente de Chucuri, where this research was conducted, farmers face difficulties finding labor (TechnoServe & ANDI, 2015), and one out of five farms have land ownership issues (Neva & Prada, 2020). Additionally, the multidimensional[1] poverty affects 45% of the population living in rural areas, a population in which 80% of rural households have low educational attainment[2] (DANE, 2018).

The agricultural practices aimed to reduce Cd absorption by cacao plants also have complex characteristics that might affect their adoption. These characteristics are the difficulties in perceiving the relative advantage of the innovations, the low visibility of their results, and its complexity. Two of the most promising practices to lower Cd uptake by cacao- applying soil amendments (Argüello et al., 2020; Ramtahal et al., 2018, 2019) and growing cacao genotypes that accumulate Cd at low concentrations (Lewis et al., 2018; Maddela et al., 2020; R. E. T. Moore et al., 2020)- are two innovations that have some of these characteristics. In the case of the soil amendments, especially regarding liming, it has been demonstrated that its effects on soil

[1] The dimensions are (1) education (2) childhood conditions (3) employment (4) health, and (5) access to public services and housing situation.
[2] In a household with low educational attainment, its members older than 15 do not get more than nine years of schooling.

properties, and consequently in the crops, are typically found within three years after liming (Li et al., 2019). Likewise, in the case of a new cacao variety, trees might take approximately six years to achieve full production (Tahi et al., 2019). Consequently, the attributes of the technologies intended to tackle Cd in cocoa need further research as they possess specific characteristics that could influence their use among farmers.

Research Questions

It is currently unknown if cacao farmers are willing to adopt agricultural practices, particularly those reported as beneficial for alleviating the Cd issue, nor its known how the regulation of this heavy metal influences such adoption decisions in Colombia. This Ph.D. research project aims to fill this research gap and contribute to understanding the adoption of agricultural practices intending to tackle Cd in cocoa crops. To this end, this research is centered around two main questions:

1. *What behavioral theories explain the adoption of innovations among cacao farmers in San Vicente de Chucur, particularly those reported as beneficial for alleviating the negative effect of cadmium accumulation in cacao?*
   i. *How does the cadmium issue influence the adoption of these innovations?*

To answer these questions, a qualitative study was conducted using the Grounded Theory (GT) methodology developed by Glaser & Strauss (1967) to construct theory grounded in data. The rationale behind using inductive reasoning to turn empirical evidence into an articulated model (the goal of GT) was 1) the lack of a consistent explanation for why farmers adopt innovations, 2) the unique characteristics of the farmers, their context, and the innovations studied, and 3) the novelty of the Cd issue.

Structure of the Dissertation

This dissertation has five chapters. The following chapter 2 summarizes literature related to the adoption of innovations on perennial crops. Chapter 3 describes the methodology used throughout the study, including descriptions of the qualitative methods utilized and the details of the survey development and chapter 4 presents the findings. Chapter 5 includes conclusions, discusses the results and highlights their relevance for advancing the theory and practice of the diffusion of innovations in cacao.

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CHAPTER 2

REVIEW OF LITERATURE

Introduction

The relevance of the adoption of innovations research to the public policy debate in the Colombian agricultural sector remains high. Understanding how farmers react to new ideas is essential for those concerned with agricultural development and those who develop and transfer technology. In the humid tropics, where millions of smallholder farmers depend on perennial crops, farmers' decisions do not usually depend on a year-to-year basis (Schroth & Ruf, 2014). Currently, research on the diffusion of innovations on perennial crops, including cacao, is limited (Duque, 2018), therefore, synthetizing adoption studies is a critical endeavor to learning about the diffusion of innovations in perennial agricultural systems.

This literature review focuses on the phenomenon of the adoption of innovations in perennial crops in the tropics. Specifically, it aims to answer the question: *What factors influence the adoption of innovations on perennial crops among small farmers in the tropics?* To answer this question, two strategies were utilized. First, a comprehensive search strategy guided the identification of 209 articles. Second, a meta-analysis was used to quantitatively synthesize only results of empirical analyses that focus on the adoption of agricultural technologies on perennial crops. In this latter phase, vote-counting-based meta-analysis was applied to nine studies to evaluate the inclusion and significance of the factors that explain the adoption of innovations. To my knowledge, this document represents the first systematic meta-analysis of the adoption of agricultural innovations in perennial crops in the humid tropics.

Comprehensive search strategy

The first strategy used to answer the central question of this review involved a systematic approach to reviewing the literature. I followed Booth et al.'s (2016) idea of a literature review in which the methods used to search, select, and evaluate research are explicit and reproducible. My systematic approach to review the literature is based on the following: 1) the book Systematic Approaches to a Successful Literature Review (Booth et al., 2016), and 2) a preparation checklist for structured literature reviews (Ghezzi-Kopel & Fournier, 2019).

To identify essential search items, the research question was revisited to distinguish the fundamental elements or concepts of the question. As guidance, three elements of the PICOC[3] framework suggested by Booth et al. (2016) were used to unpack the review question into its components. Specifically, the 'Population' (small farmers), the 'Outcome' (adoption of innovations), and the 'Context' (perennial crops in tropical regions) elements were applied. Once these concepts were identified from the question, the various synonyms for each concept were listed, as presented below:

- *Small farmers*: small*[4] farm*, peasants, and agricultural worker.

[3] PICOC accounts for Population, Intervention or Exposure, Comparison, Outcome, and Context. The PICOC framework was suggested by Perricrew and Roberts, 2006, as cited in Booth et al., (2016, p. 86).
[4] The symbol * was added to the root of some words to find all forms of that word (i.e., small* farm* to search for small*holder*; small-*scale*; small*s*, and farm*ers*-farm*s*)

- *Perennial*: tree crops. The specific names of major tree crops included in Nair's (2010) book were also included. These species were Arecanut, Cashew Nut, The Coconut Palm, Cinchona, Cocoa, Coffee, Oil Palm, Rubber, Tea, and Wattle. The researcher also considered it relevant to include the terms ‘Agroforestry’ and ‘Forestry.’
- *Tropical regions*: tropic*, and tropic* region*
- *Adoption of innovations*: diffusion of innovations, and adoption of technology.

The final step of the comprehensive search strategy was to incorporate Boolean Operations. Boolean logic denotes the simple concept of combining search terms using the words AND, OR, NOT (Boolean Operators) to devise a search strategy (Booth et al., 2016). The final search was accomplished using the terms presented below:

> *(small* farm* OR (peasant) OR (agricultural worker) AND perennial OR (tree crop*) OR (arecanut) OR (cashew) OR (coconut) OR (cinchona) OR (cocoa) OR (coffee) OR (oil palm) OR (rubber) OR (tea) OR (wattle) OR (agroforestry) AND tropic* OR (tropic* region*) AND adoption innovations OR (diffusion of innovations) OR (adoption of technology))*

The literature search of three databases was conducted: CAB Abstracts[5], ERIC (ProQuest)[6], and AGRICOLA[7]. In all cases, the search strategy described below was copied into the search boxes of each of the three databases. The search, conducted in April 2022, resulted in 9,562 documents (9,385 in ERIC, 173 in CAB Abstracts, and 4 in AGRICOLA). However, the final number of studies included in the review was reduced to 209 articles, among which only

[5] https://www.cabdirect.org/
[6] https://www.proquest.com/eric
[7] https://agricola.nal.usda.gov/

nine were quantitatively analyzed using the vote-counting technique. The inclusion and exclusion criteria utilized for the screening process are described next:

- **Types of studies:** The review included only research articles. The databases platforms allowed to refine the search by utilizing these inclusion criteria in which books/book chapters, bulletin, conference papers/proceedings, and miscellaneous were excluded.
- **Date of the study:** Articles published in the previous ten years (after 2010) were selected. A total of 71 articles from the CAB Abstracts database met the aforementioned inclusion criteria. Because all the articles from the AGRICOLA database were published before 2010, none of its papers were included in the review. On the other hand, the number of articles in the ERIC database was unmanageable, as 3,454 documents still met the inclusion criteria. Therefore, for this previous database, it was necessary to filter the results based on the type of journal.
- **Journals:** To narrow down the number of articles from the ERIC database, only four journals were included in this review. These were (1) Journal of Agricultural and Extension Education, (2) Journal of Extension, (3) Journal of agricultural education and (4) Journal of rural studies. After this inclusion criterion was added, 138 peer-reviewed articles from these four journals were selected.

Vote-counting meta-analysis

The vote-counting methodology was implemented to summarize the findings across studies approaching the phenomenon of the adoption of innovations in perennial crops. By doing this, it was possible to identify which explanatory variables have been used by recent studies and test whether those explain differences in farmers' adoption behaviors. Although the vote count methodology is a type of meta-analysis with its limitations (Combs et al., 2011), it has been useful for identifying relevant variables exploring a phenomenon of interest. As an illustration, Pattanayak et al. (2003) used the vote-counting methodology to identify the factors explaining the adoption of agroforestry, while Floress et al. (2019) did so to find the variables associated with family forest owner actions.

Two hundred and nine studies were selected for possible inclusion in the vote-counting analysis. This number, resulting from applying the previously described inclusion criteria during the comprehensive search strategy, was finally narrowed to nine articles to which the vote-count methodology was applied. The remaining 200 articles were excluded from this review because they were not quantitative empirical studies[8] focusing on the adoption of agricultural innovations in perennial crops among farmers from tropical regions.

The screening process of these 209 studies began with examining the titles of the articles. Non relevant titles were excluded. To this end, the citation of the articles in "txt" format was exported and then copied into an Excel file. Then, the title of each article was analyzed. The rationale for its inclusion or rejection based on the title was reported for each article. In 114 cases, it was impossible to judge the title's relevance alone. Therefore, the abstracts were revised to determine their inclusion. In 37 cases, it was necessary to examine the full text of the

[8] For an empirical quantitative study, the author refers to articles that use household survey data analyzed using statistical methods to explain the adoption behaviors.

publications to determine whether the inclusion criteria had been met. Complete detail of the inclusion and exclusion methodology of the articles based on their titles, abstracts, and content is provided in APPENDIX A.

Table **1** describes the nine studies included in this review regarding the author(s), year, location, agricultural innovation studied, statistical model, and the perennial system. The studies are predominantly from Africa; China is the only country outside the African Continent where research that fit the search criteria was conducted. The perennial systems covered were agroforestry (3 studies), banana and plantain (3 studies), rubber (2 studies), oil palm (1 study), and coffee (1 study).

Vote-counting procedure

Variables used to explain the adoption of innovations were identified for each study. Vote-counting method was applied to each explanatory variable and for each variable within each study it was determined whether there was a statistically positive or negative relationship with the adoption decision. The cases when insignificant correlations (*p*-values <.05) were found were also identified, as with the circumstances when a study did not report results for a particular variable. In this way, the vote count methodology involved the coding of three possible outcomes of the effect of the explanatory variables on the adoption of agricultural innovations: positive significant, negative significant, or not significant relationship.

Table 1: Description of the studies included in the vote-counting.

Author (s) and year	Country	Statistical Model	Sample Size	Innovation/Type of investment	Perennial System	Origin of conceptual model	Categories of explanatory variables
Nkomoki et al., 2018	Zambia	Probit	400	Agroforestry	Agroforestry	Review of literature	Household head characteristics; Household characteristics; Farm characteristics; Institutional characteristics
Assoumou Mezui et al., 2013	Cameroon	Probit	208	Hybrid of oil palm	Oil Palm	Review of literature	-
Ainembabazi & Mugisha, 2014	Uganda	Descriptive statistics	356	Row planting; crop spacing; fertilizer use; improved crop varieties; pest and disease control; post-harvest handling	Coffee and Banana	Review of literature	Farmers characteristics. Characteristics of extension link farmer
Mponela et al., 2016	Malawi, Mozambique, and Zambia	Probit	320	Agroforestry as a technology within Integrated Soil Fertility Management Technologies	Agroforestry	Review of literature	-
Ruf, 2012	Ivory Coast	Correlation coefficient	174	Clonal rubber	Rubber	Boserupian mechanism of innovation	-
Qi et al., 2021	China	Logistic model	102	Variety identification, fertilization, sharpening, and tapping technologies	Rubber	Review of literature	Smallholder characteristics; Cultivation context; Technical training and technological services
Nyirahabimana et al., 2021	Kenya and Uganda	Weibull distribution	237	Agroforestry as a soil and water conservation practice	Agroforestry		Socio-economic and demographic characteristics
Mwombe et al., 2014	Kenya	Logistic model	116	Tissue Culture	Banana	Review of literature	-
Weyori et al., 2018	Ghana	Ordinary Least Squares	250	Plantain variety	Plantain	Non-separable model with missing markets	Household characteristics; Wealth indicators; Access to market and information

Results of the vote-count meta-analysis are presented in **Table 2**. The second column of the table includes the total number of studies for each variable. In contrast, columns three and four include the number of papers that identidied variable with a significant positive or negative influence on the adoption of innovations. Column 6 of Table 2 includes the percentage of studies including each variable and the average of studies that included each of the six categories used to group the variables.

Researchers follow diverse methods when categorizing the variables explaining the adoption of innovations. This categorization depends on the researchers' point of view. Thus, the categories of factors that explain technology adoption could vary if researchers base their selection of variables on economic, sociological, or psychological issues, to name a few. As a way of illustration, Pattanayak et al. (2003), using their economic lenses, framed the variables explaining the adoption of agroforestry into five categories: (1) preferences, (2) resource endowments, (3) market incentives, (4) biophysical factors, and (5) risk and uncertainty. On the other hand, Rogers' (2003, p.11) Diffusion of Innovation theory, from a sociological perspective, identifies four main elements in the adoption of innovations which are (1) the innovation, (2) the communication channels used by participants, (3) the social system, and (4) time. In this way, common categories used to frame explanatory variables using Roger's theory are the attributes of innovations (relative advantage, compatibility, complexity, trialability, and observability) and the innovativeness of the members of a social system.

In this literature review, the categorization of the variables used in **Table 2** reflects the categories used by the authors of the papers. In some cases, however, the studies did not group the explanatory variables into specific categories (i.e., Assoumou Mezui et al., 2013). In this way, the categories under which the variables were grouped are (1) household characteristics, (2) Wealth Indicators, (3) Access to Information, (4) Access to Markets, (5) Farm Characteristics, and (6) Extension Characteristics

Table 2*:* Votes on the determinants of adoption of agricultural innovations in perennial systems

Variable	Included	Significant		Insignificant	Included %	Sig. %
		Positive	Negative			
Household Characteristics					**39%**	**44%**
Age	8	1	2	5	89%	38%
Gender (man=1)	7	2	0	5	78%	29%
Education Level	7	0	1	6	78%	14%
Household Size	5	0	0	5	56%	0%
Membership in Farmer Group	4	0	2	2	44%	50%
Farming Experience	3	0	0	3	33%	0%
Marital Status	3	0	0	3	33%	0%
Local Leader or Teacher (yes=1)	1	1	0	0	11%	100%
Dependency Ratio	1	0	1	0	11%	100%
Intention to Increase Size of Plantation	1	1	0	0	11%	100%
Soil Fertility Perceptions	1	0	1	0	11%	100%
Climate Change Awareness	1	0	0	1	11%	0%
Access to Information					**20%**	**39%**
Access to Extension	6	1	1	4	67%	33%
Use of Information and Comm. Tech.	1	1	0	0	11%	100%
Network Index	1	1	0	0	11%	100%
Radios Owned	1	0	0	1	11%	0%
Cellphones Owned	1	0	0	1	11%	0%
Access to Media	1	0	0	1	11%	0%
Farm Characteristic					**17%**	**75%**
Cultivation Area	2	0	1	1	22%	50%
Location	2	1	0	1	22%	50%
Land Availability	1	1	0	0	11%	100%
Age plantation	1	1	0	0	11%	100%

Table 2 *continued*

Variable	Included	Significant		Insignificant	Included %	Sig. %
		Positive	Negative			
Wealth Indicators					**23%**	**32%**
Off-farm Income*	5	1	0	4	56%	20%
Farm Size	4	0	0	4	44%	0%
Livestock Units Owned	3	0	0	3	33%	0%
Income	2	1	0	1	22%	50%
Land Ownership	2	1	0	1	22%	50%
Assets	1	1	0	0	11%	100%
Price of Product	1	1	0	0	11%	100%
Livestock Loss	1	0	0	1	11%	0%
Crop Loss	1	0	0	1	11%	0%
Bicycles Owned	1	0	0	1	11%	0%
Access to Market					**19%**	**28%**
Distance to Market	3	1	0	2	33%	33%
Access to Credit	3	0	1	2	33%	33%
Access to Inputs Supply	1	1	0	0	11%	100%
Point of Sale (1=Farmgate; 0=Market)	1	0	0	1	11%	0%
Number of Accessible Markets	1	0	0	1	11%	0%
Production Sell (1=Individual; 0=Group)	1	0	0	1	11%	0%
Extension Characteristics					**11%**	**33%**
Experience (yes=1)	1	1	0	0	11%	100%
Gender Extension (man=1)	1	0	0	1	11%	0%
Extension Local leader or teacher (yes=1)	1	0	0	1	11%	0%

*Note**: The variables (1) "income other sources" in Mponela et al. (2016) and Nyirahabimana et al. (2021), (2) "off-farm income" in Weyori et al. (2018), and (3) "main activity: off-farm activity and farm activities" in Assoumou Mezui et al. (2013) and Ainembabazi & Mugisha (2014) were merged into a single variable titled "off-farm income."

What does explain the adoption of innovations in perennials?

Identifying the factors influencing adoption of innovations is an essential objective of this study. Therefore, the contribution of the variables included in the empirical models from the nine studies is described below.

Household characteristics

An average of 39% of the selected studies used household characteristics to explain the adoption of agricultural innovations in perennial systems. Specific measures of household characteristics such as age, gender, and education level were the most included in the reviewed studies.

Age of farmer: Eight out of the nine papers incorporated the age of the household head as an explanatory variable of the adoption of innovations. However, in only three out of the eight papers, the authors found that age significantly influenced the adoption of agricultural innovations in perennial crops. Among the studies that found a significant relationship between age and adoption behaviors, there was no agreement on the direction of this relationship. For instance, Qi et al. (2021) found that age explained the adoption of technologies in rubber crops. However, their findings indicate that the influence of age on adoption behaviors depends on the type of technology. In three out of the four technologies studied by Qi et al. (2021), age was negatively correlated with their adoption. The previous was the case of the adoption of fertilization technologies, sharpening technology, and variety identification technology. In contrast, for the fourth studied innovation (tapping technology), Qi et al. (2021) demonstrated that older farmers were more likely to adopt it than their younger counterparts.

Divergence in the direction of the relationship between age and adoption of innovations was also found across the two remaining studies. Mwombe et al. (2014) found that the adoption of tissue culture among banana farmers in Kenya was significantly higher among older farmers. In contrast, Nyirahabimana et al. (2021) detected a significant negative relationship between the age of the household head and the adoption of agroforestry systems among Kenyan and Ugandan farmers. The remaining five studies that included age as an explanatory variable (Ainembabazi & Mugisha, 2014; Assoumou Mezui et al., 2013; Mponela et al., 2016; Nkomoki et al., 2018; Weyori et al., 2018) did not find a significant relationship between this variable and adoption of innovations. However, in terms of the *dependency ratio*[9], Weyori et al. (2018) found that households with a lower dependent population were more likely to adopt improved plantain varieties. More precisely, the previous authors found that a 1% increase of dependents in the household decreased the probability of adoption by 3%.

Gender: The proportion of males and females in the household was included in 78% of the studies. Among these articles, 29% found a significant relationship between gender and the adoption of agricultural technologies. For example, farms headed by women had a 12% lower probability of adopting agroforestry (Nkomoki et al., 2018). As a potential explanation, the previous authors suggest that, due to gender differences in labor roles, female household heads may not have felt secure practicing agroforestry. Similarly, Ainembabazi & Mugisha (2014) found that gender explained the adoption of innovations as the percentage of male farmers was

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[9] Dependent population in a household divided by its working population. The dependent population is usually made up of children and elders, while the active people are between 15 and 65.

significantly higher for the group of adopter farmers (53%) than for those who rejected these innovations (44%).

Nonetheless, according to Assoumou Mezui et al. (2013), gender was not significantly related to adopting the oil palm variety. Comparatively, for Mponela et al. (2016), there was no significant correlation between this variable and the adoption of agroforestry. Likewise, Nyirahabimana et al. (2021) did not find any critical relationship between the adoption of agroforestry and gender. Similar results were obtained by Mwombe et al. (2014). They did not find a significant relationship between gender and the adoption of tissue culture bananas as planting material. In plantain, a similar agricultural system to banana, Weyori et al. (2018) did not find gender a significant factor in the adoption of the improved varieties studied.

Education Level: Together with gender and age, the education level of the household head was among the top three variables included in the reviewed studies. Seven out of nine papers had education level as an independent variable in their models. Nonetheless, in six out of these seven articles, the authors did not find a significant influence of education level on the adoption of innovations (Ainembabazi & Mugisha, 2014; Mponela et al., 2016; Nkomoki et al., 2018; Nyirahabimana et al., 2021; Qi et al., 2021; Weyori et al., 2018). The only study that found a significant influence of education level on the dependent variable was from Mwombe et al. (2014). The previous authors, however, found that the adoption of tissue culture bananas among farmers was negatively correlated with their education level. Even though Mwombe et al. (2014) reported that the level of education was a significant constraint to the use of information and communication technologies, a key variable explaining the adoption of tissue culture bananas, the authors fell short of discussing the negative relationship between education level and adoption behavior.

Household Size: Five out of the nine articles studied the role of the number of household members on the adoption of innovations in perennial crops (Assoumou Mezui et al., 2013; Mponela et al., 2016; Nkomoki et al., 2018; Nyirahabimana et al., 2021; Weyori et al., 2018). However, none of these found a significant relationship between household size and the adoption of agricultural technologies.

Membership in Farmer Group: Half of the four studies that considered group membership as an explanatory variable did not find this variable helpful in explaining the adoption of innovations. More specifically, Nkomoki et al. (2018) and Qi et al. (2021) did not see any effect of participating in cooperative organizations on adopting innovations in agroforestry and rubber crops, respectively. Contrary to these studies, Mponela et al. (2016) found that group membership negatively influenced the adoption of agroforestry as an integrated soil fertility management technology. This result was also reported by Nyirahabimana et al. (2021). They found that group participation reduced the adoption of agroforestry as a soil and water conservation practice.

Farming Experience: None of the three studies that used farming experience in their models found this variable helpful to explain the adoption variability when a p-value $<.05$ was used. According to Nkomoki et al. (2018), the higher the number of years spent in farming, the higher the likelihood of adopting agroforestry (This previous correlation was only found to be significant at a p-value$<.1$). In particular, a one-year increase in farmer experience showed a

0.5% higher likelihood of adopting this practice (Nkomoki et al., 2018). When focusing specifically on farmers' experiences with technology rather than farming experience per se, Ainembabazi & Mugisha (2014) found that the relationship between such experience and technology adoption tended towards an inverted-U curve. This 'inverted-U' shape indicates that the adoption rate of agricultural technology was lower at lower levels of the farmer's experience with the new technology. Still, as the farmer gained more experience with the technology over time, the adoption rate first increased at a decreasing rate before declining at higher levels of farmer's experience. However, Ainembabazi & Mugisha (2014) and Weyori et al. (2018) suggested that farmers' experience did not influence the adoption of agricultural innovation in perennial systems.

Marital status: One-third of the reviewed studies included the marriage status of the household head as an explanatory variable in their studies (Ainembabazi & Mugisha, 2014; Assoumou Mezui et al., 2013; Mwombe et al., 2014). However, none of these studies found that marital status was statistically significant.

Local Leader or Teacher: Ainembabazi & Mugisha (2014) found that the percentage of farmers who considered themselves local leaders or teachers was relevant to explaining differences in adoption behaviors. According to these authors, among the farmers who viewed themselves as regional leaders or teachers, the percentage of technology adoption (36.3%) was higher than for those who did not belong to this group (28%).

Intention to Increase Size of Plantation: Farmers' intention to increase the size of their plantation was found to be, according to Assoumou Mezui et al. (2013), significantly correlated to the adoption of the Tenera hybrid oil palm among smallholder farmers in Cameroon. As reported by Assoumou Mezui et al. (2013, p.107), when farmers wanted to create a large-scale plantation, they usually ordered improved seeds from local sources who provided the farmers with the Tenera hybrid of reliable quality.

Soil Fertility Perceptions: Mponela et al. (2016) found that a variable negatively associated with agroforestry adoption was farmers’ perception of having land that does not respond to inputs. As reported by these authors, farmers who perceived that their land required minimal fertility amendments tended to have a lower likelihood of using such technologies. The authors suggested that this negative and significant relationship occurred because farms requiring minimal fertility amendments might have “responsive soils,” which encouraged farmers to continue adopting agroforestry, among other integrated soil fertility management technologies.

Climate Change Awareness: Mponela et al. (2016) found that farmers' awareness about climate change did not influence the adoption of innovations to tackle such an issue.

Access to Information

Adopting innovations has been widely recognized in the literature as an information-seeking process. To form an attitude that leads to a decision of whether to adopt or reject an innovation, farmers must learn about the innovations through diverse communication channels. Thus, the variables measuring access to information have been highlighted as critical to understanding farmers’ adoption behaviors. In the present review, an average of 20% of the studies considered variables related to this category. Among those studies that included such variables, 39% found that they helped explain the variation in the adoption of agricultural innovations on perennial systems.

Access to Extension: The variable “access to extension” was the fourth most common variable studied. Six out of the nine articles examined the role of this variable in the adoption of agricultural technologies; however, only one of them showed a significant positive relationship between access to extension and adoption. Ruf (2012) showed how government projects[10] were critical in explaining the initial adoption of rubber among village farmers. These projects provided the information and the capital, particularly the planting material (clonal rubber), farmers needed to start a crop new to them. According to Ruf (2012), projects were also essential to let new rubber farmers know that there was a market for rubber in the country. In the same way, the absence of projects explained the period of non-adoption of rubber by farmers (Ruf, 2012).

Regarding technology adoption among rubber farmers, Qi et al. (2021) found that participation in technical training did not necessarily influence the adoption of rubber technologies. According to Qi et al.'s (2021) results, access to extension only had a positive and significant influence on adopting one out of the four analyzed technologies. In the three remaining technologies, however, the direction of the relationship was negative and, in one case, significant. A similar inconsistency in the relationship between access to extension and adoption

[10] Note that in this research access to projects is considered as access to extension. This rationale is supported by Christoplos' (2010, p.2) definition of extension as “an admittedly amorphous umbrella term for all the different activities that provide the information and advisory services that are needed and demanded by farmers and other actors in agrifood systems and rural development.” Thus, programs might also deliver information to rural clientele in the same way extension systems do so. Ruf's (2012) paper is the only one that considered access to projects as an independent variable. The rest of them studied the influence of access to extension on the adoption of innovations.

of innovations on perennials was reported by Ainembabazi & Mugisha (2014), who examined how the adoption rate responded to the hours of contact between farmers and extension agents. In this case, the authors reported that extension service significantly enhanced the adoption rate in banana and rice enterprises. However, it significantly reduced the adoption rate in pineapples, while the relationship was not significant for coffee and maize.

Focusing on the oil palm cropping system, Assoumou Mezui et al. (2013) found no significant association between extension services and the adoption of the palm variety studied. Similarly, Nyirahabimana et al. (2021) nor Mponela et al. (2016) found a statistically significant relationship between the access to extension and the adoption of agroforestry.

Use of Information and Communication Technologies: Mwombe et al. (2014) found a significant positive relationship between the use of ICTs and the adoption of tissue culture among banana farmers. However, Weyori et al. (2018) did not find that *Access to Media* influenced the adoption of enhanced plantain varieties, consistent with Mponela et al. (2016), who did not find that *owning a radio or a cellphone* influenting agroforestry adoption. In terms of the *Network Index*, Weyori et al. (2018) found that having a solid social network played a significant role in reducing the barriers to plantain varieties adoption in Ghana.

Wealth Indicators

Measures of wealth indicators, such as income and assets, were included in 23% of the reviewed papers. Among those studies that used wealth indicators, 32% found that their inclusion was beneficial in explaining the adoption of innovations. The top-three variables measuring wealth that were included in the studies were off-farm income (considered by 56% of the authors), farm size (44%), and livestock units owned by farmers (33%).

Off-farm income: Only one out of the five studies that considered off-farm income in their models found that this variable helped explain small farmers' adoption behavior. In contrast, Nyirahabimana et al. (2021) did not find any significant relationship between access to off-farm income and the adoption of agroforestry. Similar results were obtained by Mponela et al. (2016), who also studied the influence of off-farm income on agroforestry adoption. Likewise, neither Assoumou Mezui et al. (2013) nor Weyori et al. (2018) found that having an income source outside the farm affected the adoption of an oil palm variety and a plantain variety, respectively. In contrast, Ainembabazi & Mugisha (2014) found that the adoption of agricultural technologies in coffee and banana crops was higher among those households with a higher number of members engaged in off-farm activities.

Farm Size: None of the four studies that included farm size as an explanatory variable in their models found that this variable significantly influenced the adoption of innovations (Ainembabazi & Mugisha, 2014; Mponela et al., 2016; Nyirahabimana et al., 2021; Weyori et al., 2018). One of these previous authors, Mponela et al. (2016), neither found that *Land Ownership,* another wealth indicator, had a significant relationship with agroforestry adoption among small farmers. However, according to Nkomoki et al. (2018), households under customary tenure (insecure land tenure system) had a 17.2% lower probability of adopting agroforestry than households under the statutory scheme.

Livestock Units Owned: The number of livestock units owned by a household has been considered by various authors as a wealth indicator that could explain the adoption of agricultural technologies. In this review, however, none of the three studies found a significant relationship between livestock owned by a household and their adoption behavior (Mponela et al., 2016; Nyirahabimana et al., 2021; Weyori et al., 2018). The variable *Livestock Loss*, also included by Mponela et al. (2016) as a potential determinant of the adoption of agroforestry, was not correlated to farmers' adoption decisions. The same occurred with *Crop Loss*, a wealth indicator variable included in Mponela et al.'s (2016) probit model.

Income: Only two out of the nine reviewed studies included income as a potential explanatory variable. In one of these two studies, Qi et al. (2021) did not find a significant relationship between farmers' income and the adoption of agricultural innovations among rubber farmers. In contrast, Mwombe et al. (2014) identified a significant positive relationship between revenue and the adoption of banana tissue culture. According to Mwombe et al. (2014), those respondents with high incomes could purchase tissue culture suckers from remote research locations. This previous result was consistent with Weyori et al. (2018), who found that *household assets* were significantly and positively correlated with the adoption of improved plantain varieties. However, including the number of *bicycles owned* as a wealth indicator did not help explain the variations in the adoption of agroforestry (Mponela et al., 2016).

Produce price: Markets play a crucial role in the adoption of innovations. In the case of the diffusion of rubber crops, Ruf (2012) found that after farmers adopted this type of crop due to the influence of extension projects (see access to extension above), rubber prices determined the adoption of this crop. Ruf (2012) used the Boserupian theory of innovations that argues that "necessity is the mother of invention," which means nothing but that the primary driving force for the adoption of rubber was the need, reflected in the price (the higher the demand-need, the higher the price).

Access to Market

An average of 19% of the studies used the variable access to market variables to explain technology adoption in perennial crops. Specific measures of household characteristics such as distance to market and access to credit were the most included in the reviewed studies.

Distance to Market: One-third of the reviewed studies included this variable in their model. Among those, only Weyori et al. (2018) found a significant relationship between the farms' distance to market and the adoption of agricultural technologies. According to the previous authors, the larger the distance to a market, the higher the likelihood that farmers would adopt improved plantain varieties. Weyori et al. (2018) also found that the significance and direction of this relationship were the same for the intensity of the plantain varieties adoption, measured as the percentage of the area established with specific plantain varieties. While the authors affirmed they expected a reverse direction of the relationship of the variables, they indicated that a possible explanation is that retailers in the field buy the plantains, so farmers do not have to travel to market centers to sell the product. The two other authors that included the variable 'distance to market' in their models were Ainembabazi & Mugisha (2014) and Mponela et al. (2016). In none of their studies the authors find any significant relationship between the distance to market and the adoption of innovations in the perennial systems (coffee/banana and agroforestry, respectively). Furthermore, Mponela et al. (2016) did not find that the *point of sale* had a connection with the adoption of agroforestry. The previous results are consistent with Nyirahabimana et al.'s (2021) results that suggest that the *number of accessible markets* did not affect the adoption of agroforestry among small farm holders.

Access to credit: Three articles evaluated the influence of having access to credit on adopting innovations. Only one found a significant relationship between this explanatory variable and the dependent variable. While one might think that access to credit enhances the adoption of innovations, the results of Nkomoki et al. (2018) showed the contrary. Households with access to credit were 24% less likely to adopt agroforestry than those without access to credit. Because Nkomoki et al. (2018) found an opposite effect for other practices, these authors commented that farmers opted to use credit on labor demanding practices (assuming that agroforestry was not). In contrast, Mponela et al. (2016) did not find any significant correlation between the adoption of agroforestry and having credit constraints, consistent with those of Nyirahabimana et al. (2021), who also studied agroforestry adoption.

Access to Inputs Supply: (Weyori et al., 2018) found that having access to input supply positively influenced the intensity of adoption of an improved plantain variety. Under those circumstances, the previous author indicated that access to farm input all year round is essential to understand the variation in the total farm size allocated to high-yielding varieties relative to traditional plantain varieties.

Farm Characteristics

Measures of farm characteristics, such as cultivation area, location, land availability, and the age of the plantation, were included in 17% of the reviewed papers. Among those studies that used wealth indicators, 75% found that their inclusion helped explain the adoption of innovations. The top-two variables assessing farm characteristics included in the studies were cultivation area and farm location, each analyzed in two articles.

Cultivation Area: Mwombe et al. (2014) found that the banana acreage negatively influenced the adoption of tissue cultures among farmers. According to the previous authors, this significant relationship could mean that those respondents with larger cultivated areas had good planting material. Therefore, they were less willing to purchase the studied innovation. In contrast, Assoumou Mezui et al. (2013) did not find any significant relationship between the adoption of a hybrid oil palm and the acreage of this crop.

Location: Mponela et al. (2016) found that the site influenced the adoption of agroforestry. In this way, farmers from Malawi, Mozambique, and Zambia differed in their levels of adoption of agroforestry. In contrast, Nyirahabimana et al. (2021) did not find that the location of the households (Kenya and Uganda) influenced the adoption of agroforestry.

Land Availability: According to Assoumou Mezui et al. (2013), the authors of the only paper that considered this variable, land availability was one of the two factors that significantly determined the adoption of the oil palm hybrid. As reported by the authors, the availability of arable land in a forested area positively influenced farmers' decisions to adopt this innovation.

Age of plantation: Qi et al. (2021) found that the older the rubber plantation, the more likely farmers implemented technologies. Interestingly, this relationship's direction and significance are held for all the four innovations studied by the previous authors. Qi et al. (2021, p.333) reported that the longer the year of rubber planting, the more inclined the smallholders were to adopt fertilization, tapping, and variety identification technologies.

Extension Characteristics

Ainembabazi & Mugisha (2014) were the sole authors that studied the role of extension characteristics on the adoption of agricultural technologies in perennial crops. According to their paper, extensionists' *experience* in technology dissemination positively influenced the adoption of innovations. In contrast, the authors did not find that the *gender of the extensionist* nor their *consideration of being local leaders or teachers* influenced the adoption behavior of farmers

CHAPTER 3

RESEARCH METHODS

Introduction

Grounded theory (Corbin & Strauss, 2008) was selected as the qualitative research methodology due to the lack of knowledge regarding the variables and variables relationships that intervene in the adoption of clonal cultivars and soil amendments across cacao farmers in San Vicente de Chucuri. Two theoretical explanations, one for each innovation, were developed by following an iterative data collection and analysis process. The study was approved by the Institutional Review Board of the Pennsylvania State University (IRB: STUDY00014656).

Sampling

Theoretical sampling (Corbin & Strauss, 2008) and purposeful sampling (Patton, 2002) were used to identify the participants of this research. Theoretical sampling is one of the key characteristics of GT. This sampling design poses two peculiar characteristics. The first one is that it is a method of data collection based on concepts[11]. In other words, it is concepts that are sampled in data. The second unique characteristic of this sample design is that it is responsive to the data rather than established before the research begins, a feature that makes the sampling process open and flexible (Corbin & Strauss, 2008). Following the principle of theoretical sampling, data

[11] Concepts are the building blocks of theory. Concepts are words that stand for groups or classes of objects, events, and actions that share some major properties (Corbin & Strauss, 2008, p. 45).

collection and data analysis went hand in hand, as it is described in the data collection/analysis chronogram (APPENDIX B). The initial data collection was immediately followed by data analysis. Then, data analysis led to the development of concepts, which generated questions that led to more data collection.

In some cases, snowball sampling and maximum variation sampling (Patton, 2002) was used to purposefully locate information-rich cases that could provide valuable data for developing the properties and dimensions of the concepts. For example, the first cacao farmer interviewed recommended that the researcher should talk with participant 2, who in turn provided the researcher with the contact information of participant 4 (See APPENDIX C for the details on how participants were identified). Theoretical sampling and snowball sampling were helpful in collecting the data needed to develop the theories explaining adoption decisions across cacao in San Vicente (Corbin & Strauss, 2008; Patton, 2002).

Even though the population of interest is cacao farmers, additional participants outside this population were interviewed to answer the questions that arose during the data analysis process. As an illustration, to develop the concept of "availability of soil amendments," Participant 9, who worked as an extension agent in San Vicente, suggested talking with P10 and P12, who are soil amendment providers in this municipality. Therefore, extension agents, experts on soil amendments, soil amendment providers, planting material producers, and cocoa farmers, the population of interest for this research, were among the respondents from which data were collected. Though most interviewed participants provided the contact of newer respondents, participants were initially identified with help from agronomists and technicians from San Vicente. For this purpose, support was received from the National Federation of Cacao Growers'

(Fedecacao) staff and the Sales and Agricultural Promotion Department of Compañía Nacional de Chocolates, a Colombian chocolate manufacturing company. Once identified, the researcher recruited the participants by calling the potential subjects who heard about this research opportunity and voluntarily accepted to participate in the study.

The selection of the participants was primarily focused on developing the concepts rather than on seeking a sample representative of the larger population. Nonetheless, strategies were implemented to avoid the selection of a homogeneous sample of individuals. For instance, all the participants were selected because they could contribute to developing the theories (John W Creswell & Poth, 2018). Likewise, a heterogeneous sample of participants was chosen after the first drafts of the theory were developed, for which maximum variation sampling (Patton, 2002) was used. In the end, the rationale for maximizing variation in the sample was to increase the likelihood that the findings would reflect differences that would be helpful to develop the concepts of the theory and their properties.

Sample Size

A total of twenty individuals that participated in this research were sufficient to reach the point of theoretical saturation (Saldaña, 2021). Theoretical saturation indicates that no new relevant concepts are emerging and that further data collection adds little new to the process of building theory (Corbin & Strauss, 2008). However, as the researcher is the one who determines that the concepts are well developed for each specific research, the answer to how much sampling must be done to achieve data saturation is complex. A sample of fifteen participants was used as a baseline following Saldaña's (2021, p.302) input to overcome the previous issue. Based on the scarcity of new information arising from the last three interviews, sampling was completed with twenty participants, whose characteristics are described in **Table 3**.

Table 3: Participants characteristics

Participant (P)	Gender	Occupation	Clonal Cultivars Adoption	Soil Amendment Adoption	Member checking
P1	Male	Cacao farmer/nursery manager	Yes	Yes	Yes
P2	Male	Businessman/cacao farmer	Yes	Yes	No
P3	Male	Cacao farmer	Yes	Yes	No
P4	Male	Cacao farmer/cacao extensionist	Yes	Yes	No
P5	Male	Cacao extensionist/cacao farmer	Yes	No	Yes
P6	Male	Cacao farmer	Yes	No	Yes
P7	Male	Coffee extensionist	-	-	No
P8	Male	Manager of soil amendments company/coffee extensionist	-	-	Yes
P9	Male	Coffee extensionist	-	-	No
P10	Female	Soil amendments provider	-	-	No
P11	Male	Cacao extensionist	-	-	No
P12	Female	Soil amendments provider	-	-	No
P13	Male	Cacao extensionist/cacao farmer	Yes	Yes	No
P14	Male	Cacao farmer	Yes	Yes	No
P15	Male	Cacao farmer	Yes	No	No
P16	Male	Manager of soil amendments company	-	-	No
P17	Male	Cacao farmer	No	-	No
P18	Male	Forestry worker/cacao farmer	Yes	No	No
P19	Female	Cacao farmer	Yes	No	Yes
P20	Female	Cacao farmer	Yes	No	No

Data Collection

Data were collected by conducting semi-structured telephone interviews. Only in one case, a participant (P17) sent five audio recorder messages to the researcher. Three communication platforms were used to interview the participants. In twelve out of the twenty cases, the researcher used the mobile application “WhatsApp.” Five participants were called directly on their cellphone numbers using the international communication website “Llamacolombia,” which was helpful for cases in which interviewees didn’t have access to a stable internet connection. Finally, three participants were interviewed via Zoom. These interview media were chosen instead of face-to-face interviews due to budget constraints and Covid-19 limitations. Likewise, the selection of semi-structured interviews instead of structured or unstructured interviews (for differences, see Savin-Baden & Howell-Major, 2013, p. 358) was supported by the characteristics of the sampling design utilized. As part of theoretical sampling, questions about concepts constantly arose; therefore, even though the questions did not necessarily follow a set order (as in structured interview), they covered specific topics (not occurring in unstructured interviews). Under those circumstances, the researcher considered semi-structured telephone interviews the ideal type of interview.

All the initial interviews were recorded with the permission of the participants, except for the case of P12, whose interview was not recorded by their request. Patton's (2002, p. 382) tips for recording the interviews were followed. In this case, an external electrical microphone was utilized. The researcher was in a quiet place free from interruption. The recording system was tested. Finally, the researcher spoke clearly and not too fast to motivate the respondents to do the same. The average duration of the recordings was 40 minutes; once transcribed, the average length of each interview was 4,090 words. The recorded interviews were transcribed verbatim by the researcher. To increase the efficiency of the transcription process, the researcher used a foot pedal that allowed him to pause, play and rewind the recording. Also, the researcher used the software Express Scribe to slow down the recording speed to avoid interruptions while transcribing the recordings. The purpose of having the researcher do all the transcriptions, instead of having them done by a transcriber, was to offer the former an opportunity to get immersed and gain insight into the data. Transcribed interviews were entered into the NVivo qualitative data analysis software for analysis.

The data provided by participants varied along with the variation of the interview questions due to the theoretical sampling process. The initial questionnaire used to interview participants 1-4 focused on the farmers' opinions and values questions; nonetheless, experience, background, feeling, and knowledge questions (Patton, 2002) were also asked. After the data from the initial four participants were analyzed, the interview questions were modified following the cyclical data collection and analysis process that characterizes the methodology used in this study. The evolution of the interview questions asked to participants is illustrated in APPENDIX D.

Data Validation

Diverse strategies served the purpose of validating the quality of this research. These strategies were used for design consideration, data collection, analysis, and presentation. Also, the question regarding the accuracy of the present report was answered by looking at the researcher himself, the participants, and the readers, as Creswell & Poth (2018) suggest.

From the researcher's perspective, four specific strategies were undertaken to enhance credibility. In the first case, the researcher disclosed his understanding of the biases, values, and experiences he brought to the research (see positionality statement in APPENDIX E). Then, during data collection, the researcher corroborated the evidence through triangulation of multiple data sources, mainly through different methods and reliance on the literature. Thirdly, the researcher reported evidence that didn't fit the pattern of the conceptual frameworks generated to provide a realistic evaluation of the phenomena studied. Finally, guided by the principle of methodological consistency, the researcher followed the most relevant procedures of the Grounded Theory methodology.

The research participants also played a vital role in the validation strategies implemented. Qualitative research is, by nature, subjective as the researcher is the main instrument to collect data. In order to reduce the potential for researcher bias and to enhance the trustworthiness of the results, some research participants were interviewed a second time as a way to validate the preliminary findings of the study. This process, known as member checking, has been a promoted technique among qualitative researchers (i.e., Birt et al., 2016). In this research, member check interviews were conducted with five key participants. These second-round interviews had an average duration of 42 minutes. They were focused on the conceptual frameworks (Diagrams), which are a synthesized summary of the concepts influencing the adoption of innovations studied here. During the member checking process, the researcher described the phenomenon of adopting soil amendments and clonal cultivars by using interview data quotes representing the connection between the factors influencing the adoption process of each innovation. In 2 cases (P5 and P8) the interviews were conducted via Zoom, which allowed the researcher to show the diagrams. In the remaining 3 cases (P01, P06, and P19), when interviews were conducted via cellphone, the researcher verbally described both conceptual frameworks. Besides validating the accuracy of the results, the member checking process served as an opportunity to hear further comments from participants and incorporate those into the analysis for further refinement of the final theories. APPENDIX F contains the notes taken in the member-checking interviews.

The Research Context

Understanding what people do is equally important as elucidating the factors that constrain or enable such actions (Scoones, 2015). In this way, to explore the context in which cacao farmers of San Vicente made decisions, the researcher studied and reported information from secondary sources of information (books, documents, government websites). In other cases, some of the concepts obtained from participants' responses were identified as pertaining to context. In this way, providing sufficient information about the context in which the adoption of innovations took place was a strategy used in this research to enhance the trustworthiness of the data. As Creswell & Poth (2018) point out, this thick description is also intended to allow the reader to transfer the results to other settings. Under those circumstances, the researcher considered it critical to describe the research context, information that is provided at the beginning of the Results chapter.

Data Analysis

The core procedures of Grounded Theory guided the data analysis in this study. Open coding and axial coding were the methods used to conceptualize excerpts of the data and connect those emerging concepts, respectively. Constant comparison and asking questions of data were strategies for data analysis employed to explore participants' responses and stimulate conceptual thinking. Throughout the entire data analysis process, memos were written to record the thinking process and keep track of the generated ideas. Likewise, diagrams were utilized as the primary method to depict relationships between analytic concepts. That way, this research was guided by the systematic characteristics of the grounded theory approach of Juliet Corbin and Anselm Strauss (Corbin & Strauss, 2008).

Open coding was used to break data apart by delineating concepts representing blocks of raw data. As Saldaña (2021, p.148) describes, open coding is an opportunity to reflect on the content and contrasts of the data and begin taking ownership of them. Under those circumstances, the codes created using open coding were provisional and were redefined as the data analysis progressed. As concepts were being created, axial coding was utilized to relate concept categories. Even though open coding is classified by Saldaña (2021) as a first cycle coding method and axial coding as a second cycle one, the previous author emphasizes both coding methods are used simultaneously in a Grounded Theory study. Likewise, Corbin & Strauss (2008, p.198) affirm that the distinction between open coding and axial coding is artificial. For them, the core message is that even though data is broken apart (open coding), it is also necessary to put it back together (axial coding). In this way, both open and axial coding were the methods used to identify and connect the factors that influence the adoption of strategies aimed to tackle the cadmium issue in cacao in San Vicente de Chucuri.

Elucidating the concepts involved in adopting innovations was possible due to the use of two specific techniques suggested by Corbin & Strauss (2008): making a comparison of data and asking questions about data. When doing comparative analysis, new codes representing blocks of raw data were compared with existing codes for similarities and differences. This comparison made it possible to differentiate one concept from another and to identify their characteristics (properties) and the range over which such features vary (dimensions). The use of questioning was also helpful to understand the phenomenon approached in this research. When asking questions about data, the researcher followed his instincts about what seemed important to ask about. Perhaps nothing reflects the subjectivity of qualitative research better than this strategy of asking questions.

The questions asked by the researcher aimed to provide direction for theoretical sampling, particularly by focusing on the concepts whose properties and dimensions were not well developed. In other cases, the questions were intended to tune the researcher into what the data could be indicating. Thereby, asking questions and constant comparison were essential analytic tools that helped the researcher find the data's possible meaning.

During the data analysis process, memos and diagrams were used to facilitate and keep track of the analytic process. Memos are written records of analysis (Corbin & Strauss, 2008). In this way, memos reflected the coding process and the results of strategies utilized for analyzing data. Every time the researcher generated a new concept, a corresponding memo was created. The same occurred when new relationships between concepts were identified. All the memos were written in the software NVivo. Thanks to this software's features, it was possible to connect the memos with the actual responses from the participants, which was helpful later for providing a dense description of findings in which quotes from participants were utilized. A total of 83 memos were created (47 for concepts and 36 for concepts relationships). In all these memos, 9,866 words kept the tack of the ideas generated. Finally, it is essential to note that the researcher was more concerned about the habit of writing memos and doing diagrams rather than getting them decently presented. The previous explains potential grammatical errors of the memos.

Doing diagrams was not a method used as frequently as writing memos. However, diagrams, those visual devices describing relationships between concepts, were also helpful for generating interview questions. Besides serving as conceptual visualizations of the phenomena approached in this research diagrams were essential to ask questions to understand the relationship between concepts better. Accordingly, both diagrams and memos were utilized to keep track of the growing number of ideas generated throughout the research.

All the data were gathered in Spanish. The data analysis was also conducted in Spanish and English, following the recommendations provided by Nurjannah et al. (2014) and van Nes et al. (2010). As the author of this research speaks the participants' language, data was not translated before but during analysis. In this way, the researcher used English names for the codes generated from transcribed data in Spanish. Likewise, the storyline provided in the memos was written in English.

Operational definitions

Adoption of Clonal Cacao: The adoption of clonal cacao is the dependent variable of The Cacao Clones Adoption Model (CCAM). From now on, clonal cacao, cultivars of cacao, or a cacao clone, are defined in this research as an asexually propagated cacao plant. As grafting was the primary asexual propagation method used in Colombia, the adoption of clonal cultivars goes along with the adoption of grafting techniques in which the upper part (scion) of one plant (the clone) grows on the root system (rootstock) of another plant (Bilderback et al., 2014). However, the definition of cacao clone used in this research considers all cacao plants on a farm propagated via grafting from a cultivar developed by plant breeders. Under these circumstances, the concept of clonal cacao used as the dependent variable of the CCAM does not consider the clonal propagation of hybrid plants that are not registered in the ICA's National Cultivars Registry. In a future quantitative study, the degree to which farmers have adopted clonal cultivars could be expressed as the percentage of the area in cacao that farmers have established with clonal cultivars.

Adoption of Soil Amendments: The adoption of soil amendments is the dependent variable of The Soil Amendments Adoption Model (SAAM). This research focuses on the adoption of soil amendments in the broad sense. In other words, the Soil Amendment Adoption Model identifies the factors that influence the adoption of lime (including carbonates, oxides, and hydroxides), silicates, sulfates, and other soil conditioners. Nonetheless, farmers' responses usually describe soil amendments as lime, as the difference between the two concepts is vague. The recommended frequency of soil amendments application is every one to two years (Sadeghian, 2016). Therefore, those farmers who adopted soil amendments in the previous two years before the interview were considered to have adopted this innovation. If a farmer had adopted soil amendments but did so more than two years before the interview, then that situation is considered as the non-adoption of the innovation. To quantify the adoption of soil amendments, this concept could be measured as a dichotomous variable (applied/did not apply).

Donations: A donation, also named as a subsidized innovation, or an incentive, is a "direct or indirect payments of cash or in king that are given to an individual in order to encourage behavioral change" (Rogers, 2003, p.236).

Agricultural Extension and Advisory Services (AEAS): Agricultural Extension is all about improving the livelihoods and well-being of rural communities. Extension does so by putting together a set of activities that provide "the information and advisory services that are needed and demanded by farmers…" (Christoplos, 2010, p.2).

Beliefs of Using Cacao Clones on Farming Objectives: When farmers are in a state of mind of having confidence in a thing, they hold a belief in that thing. Accordingly, in San Vicente, farmers' beliefs regarding cacao clones reflected their confidence in using clonal cacao as a strategy to accomplish their farming objectives.

Access to Resources: Access to resources refers to the resources available to the farmer for adopting the innovations. Accordingly, access to resources in the framework of the CCAM refers to the capital, labor, and information required to adopt cacao clones.

Thoughtful Creativity: According to Nuthall (2009), thoughtful creativity is expressed through attitudes to new ideas. As this author describes, someone who scores low on thoughtful creativity tends to be unadventurous and conventional.

Conscientiousness Planning: Farmers who rate high on conscientiousness planning, says Nuthall (2009), take responsibilities seriously. They also tend to stick to management principles, planning well ahead of time and calculating monetary consequences before making decisions.

Farmers' Perceived Needs to Control Cadmium: When farmers perceive a need to control Cd in cacao, they feel the necessity of lowering the Cd levels to a certain level. Thus, farmers must be aware that the Cd levels at their farms are higher than they should be.

Perceived Need to Control Soil pH: A perceived need to control soil pH is a recognition, an understanding of, or a belief that there is a need to modify the pH of the soil.

CHAPTER 4

RESULTS

Introduction

The participants' descriptions provided the basis for constructing two separate frameworks explaining the adoption of the innovations studied in this research. The Cacao Clones Adoption model (

Figure *1*) illustrates the factors influencing the adoption of clonal cacao. The Soil Amendments Adoption model (**Figure 2**) does the same for the adoption of soil amendments. Both models identify the variables and the variables relationships that intervene in adopting these innovations by cacao farmers from San Vicente de Chucuri.

Farmers' adoptions behaviors took place within a socioeconomic and environmental context in which situations arose and to which farmers responded. This set of conditions (the context) ranged from the most macro-international level- to the micro-household level. In some cases, these structural conditions influenced a broader set of behaviors, such it is the case of economic and political situations. As an illustration, farmers' decisions to adopt cacao clones and soil amendments might have been influenced by a political context in which cacao was prioritized in development programs. In other cases, adoption decisions were influenced by more specific circumstances. For example, the propagation methodologies used by cacao farmers was a condition that did not seem to affect the adoption of soil amendments but the adoption of clonal cultivars. In this way, even though the models are presented separately, this results chapter describes first an overall context relevant to both innovations. After the overall context in which the adoption of innovations occurred is given, the Cacao Clones Adoption Model and the Soil Amendments Adoption Model are individually presented. Likewise, a description of the specific context in which innovations were adopted is provided for each model.

Overall Context

In order to understand the adoption of agricultural innovations among cacao farmers from San Vicente de Chucuri, an exploration of the economic, social, historical, and environmental context is needed. A description of the overall context where farmers' decisions have taken place is presented next.

Cocoa Supply, Demand, and Prices

This research was conducted in a period when cacao farmers around the world broke a global record of production, surpassing an impressive mark of 5 million tons of cocoa beans per year. Record productions were reported by the Ivory Coast, Ghana, and Ecuador, the three world's largest producers (ICCO, 2021). The good news also came from the tenth largest producer country, Colombia. In November 2021, the Colombian National Federation of Cacao Growers (Fedecacao) announced that between October 2020 and September 2021, the country's production reached a record level of 70,000 tons of cocoa (Fedecacao, 2021). This information came along with the reduction in cocoa imports and increased exports, area, and farms' productivity[12]. **Table 4** illustrates the evolution of production, area, yield, exports, imports, and the number of cacao farmers in Colombia in the past decade.

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[12] Yet, despite these gains, there is a long road towards reaching some institutions' visions suggesting a 2032 sector where the area will be 260.000 hectares, and the productivity of 900 kg or higher (i.e., Programa de Transformacion Productiva, 2017)

Figure 1: The Cacao Clones Adoption model

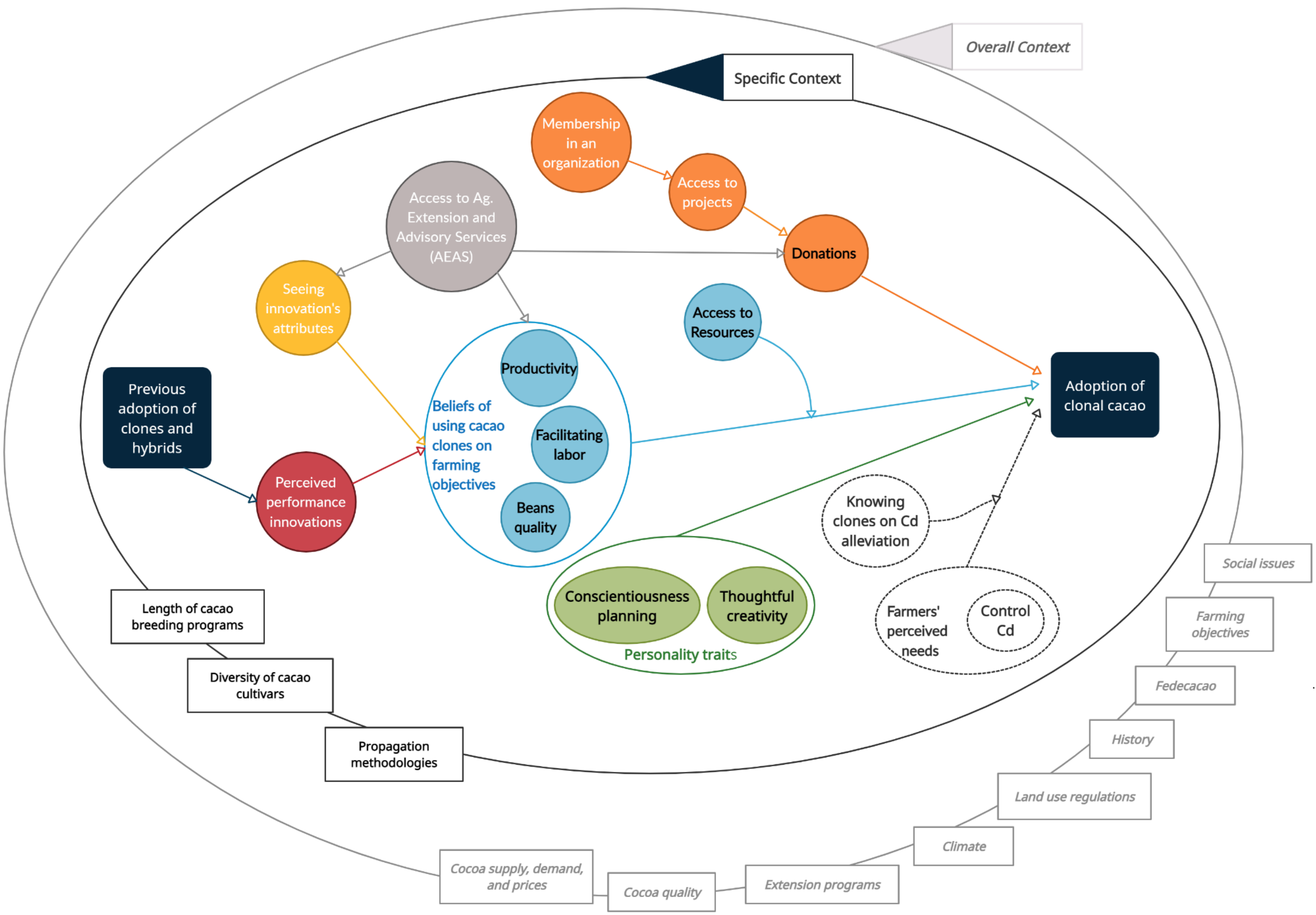


Figure 2: The Soil Amendments Adoption model

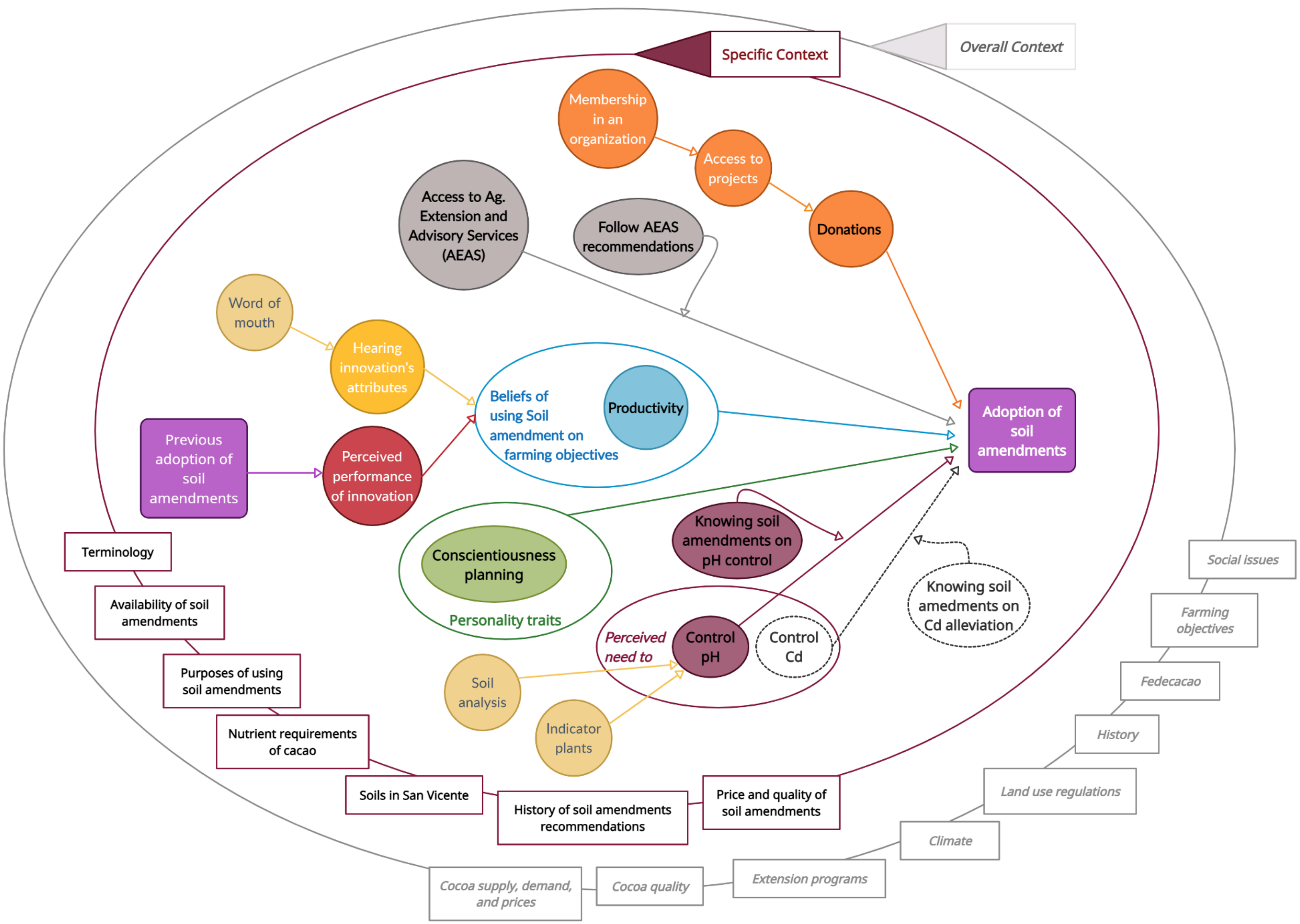
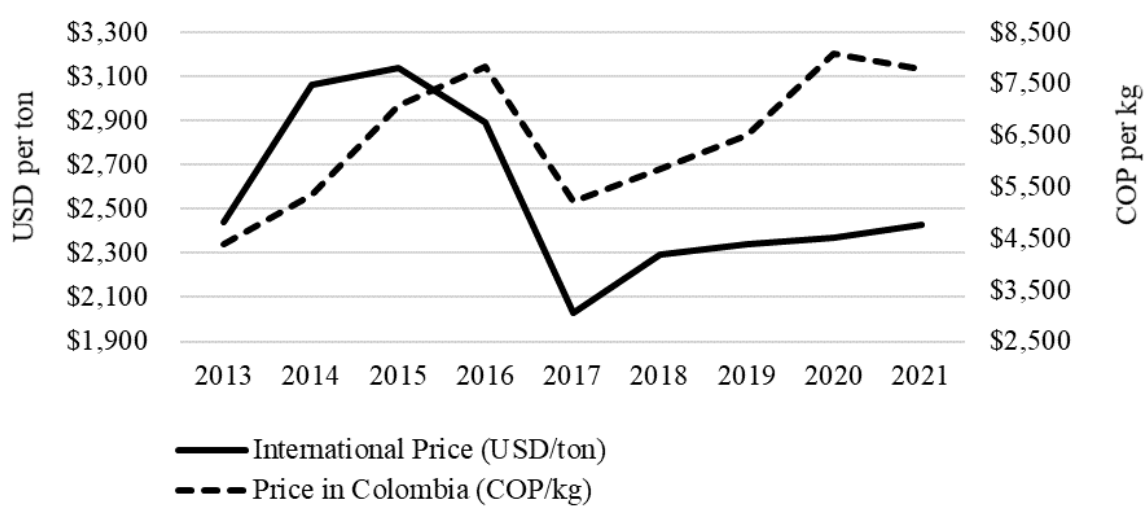


Table 4: Cocoa production, area, yield, exports, imports, and number of cacao farmers in Colombia

Variable / Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Reference**
Total Production (t)	33,482	37,718	36,118	42,294	37,203	41,670	46,739	47,732	54,798	56,785	60,535	56,867	59,740	63,416	(Baquero, 2018; Colombian Government, 2021)
Area (ha)	115,882	121,799	134,904	139,549	143,903	151,144	155,151	160,276	165,006	173,016	-	-	183,497	-	(Fedecacao, 2015; MADR, 2020)
Productivity (t/ha)	0.29	0.31	0.27	0.30	0.26	0.28	0.30	0.30	0.33	0.33	-	-	0.33	-	Using Total Production and Area, above.
Export-Cocoa bean (t)	1,884	650	2,112	5,017	2,304	4,321	7,743	8,018	13,744	10,550	11,926	7,056	9,116	11,145	(Baquero, 2018; Colombian Government, 2021)
Import-Cocoa bean (t)	12,795	5,951	5,687	6,819	8,681	1,960	2,316	6,688	5,891	4,643	488	-	402	180	(Baquero, 2018; Colombian Government, 2021; MADR, 2020)
Consumption country (t)	44,393	43,019	39,693	44,096	43,580	39,309	41,312	46,402	46,945	50,878	49,097	49,811	51,026	52,451	Using information above (Production + Import - Export)
Number of Farmers								35,000		52,569	65,341				(Baquero, 2018; MADR, 2020; Swisscontact, 2017)

Farmers' decisions also occurred in a context where the increase of cocoa production went hand in hand with increased demand and a higher price. Grindings, a measure of demand, rose 200,000 tons from 2019/20 to 2020/21, according to estimates from the International Cocoa Organization (ICCO, 2022). In this context, the global prices of cocoa have had an increasing trend for the past four years (**Figure *3***). In Colombia, the exchange rate has also influenced cocoa prices. In the past ten years, the cost of one US dollar went from less than 1,800 Colombian pesos (COP) in early 2012 to more than COP 4,000 at the end of 2021. As a result, cacao farmers in Colombia made agricultural decisions based on higher cocoa prices.

Figure 3: International and domestic cocoa prices



Note. Sources: ICCO (2022); Agronet (2022).

The recent increase in the global price of cocoa was even more beneficial for Colombian farmers. A recent study has shown that the prices paid by buyers in this country closely follow the international prices and are higher than in other cacao producing countries (Abbott et al., 2018). The previous authors showed that in 2014 when the global price of cocoa was around

$3,000/MT, cacao farmers in Colombia were receiving 2,750 while those from Ivory Coast and Ghana were being paid almost $1,750 (Abbott et al., 2018, p. 45). To understand the price differences between these countries, it is essential to look at the role of governments on the cocoa market and the way the marketing system operates. In Colombia, every cacao farmer must pay, according to law 67 of 1983, a parafiscal fund of 3% of the selling price value. However, the government does not influence the farmgate prices paid to cocoa farmers despite the mandatory fee. The previous was not the case for the two West African countries. In Ghana, for instance, the parastatal Cocoa Board (Cocobod) has a monopoly over the cocoa market, which means that it sets cocoa prices.

The marketing system in Colombia also differs from other cocoa producer countries. Colombian farmers, particularly those from San Vicente de Chucuri, transport their cacao themselves to the local buyers rather than sell it to itinerant traders, who are more likely to manipulate prices as remote farmers likely have poor information (Abbott et al., 2018). Once farmers in San Vicente are on the cacao market, they can select among dozens of traders the local buyer with the highest price. In this way, adoption decisions made by research participants occurred in a context in which cocoa prices, besides being more elevated than usual, were determined by the market.

Notwithstanding the above, some of the participants in this research identified value chain issues as one of their primary concerns. As an illustration, participant 01 emphasized that “the main difficulty of the cacao has to do with the cocoa commercialization.” This previous belief was also shared by other participants who considered that they should be receiving a higher price for their cocoa beans. Participant 02 illustrated this situation by stating that "although the current price is not bad, it should be better." Farmers' expectations of higher prices, often expressed in their desire to export their cacao, were motivated by national and international recognitions of San Vicente as a high-quality cocoa producer.

Cocoa Quality in Colombia: Threats and Opportunities

The International Cocoa Organization (ICCO), through its Ad hoc panel on fine or flavor cocoa, divided the cocoa market into two broad categories: Bulk Cocoa and Fine Flavor Cocoa (FFC). The FFC accounts for approximately 6% of total cocoa production. Because of the quality characteristics of FFC, its price is usually higher than the bulk cocoa. In 2016, the ICCO updated the list of the countries recognized as Fine Flavor Cacao producers. In total, 23 countries made the mentioned list; 18 are countries located in Latin America and the Caribbean. In the case of Colombia, 95% of the country's production was recognized as Fine Flavor Cacao (ICCO, 2019). This situation indicates that farmers' decisions occurred in a context in which access to high price markets for Colombian cacao farmers is promising. However, one specific factor affects market access for farmers in Colombia: cadmium (Cd).

Cd contents in cacao beans from Colombia are higher than those of other producer countries (Meter et al., 2019). Such being the case, Colombian cacao farmers currently face market access issues in several countries that have regulated Cd content in cacao and chocolate, particularly in Europe (Jiménez, 2015). This context of regulations is likely to influence the agricultural decisions made by farmers, especially as the potential impacts of Cd on small cacao farmers are numerous. In the first place, farmers in affected areas might receive lower prices for their cocoa beans. While prices do not depend on the Cd level, it has been recognized that Cd could be used by some clients, particularly the middleman, to create pricing advantages (Prieto, 2020). Likewise, farmers in affected areas might have to seek new markets (Bravo, León-Moreno, et al., 2021; Miranda, 2020). This impact is especially true for those farmers who directly or through cooperatives export their cocoa to markets that are now under regulations. The production costs might also be affected by this novel issue. The lab tests needed to assess Cd levels in the soil add an extra cost to the new plantation. Likewise, mitigation strategies can add additional costs and time to the cacao production system. Under those circumstances, Cd regulations generated concerns among cacao farmers in Colombia and added uncertainty to the context in which cacao farmers took decisions.

Extension Programs

Cacao farmers' decisions have been influenced by programs promoting social development. Of particular importance were the projects in which cacao was used as an alternative to substitute illicit crops. Even though San Vicente has not been a significant producer of coca (*Erythroxylum coca*), from which cocaine is obtained, this municipality has benefitted from programs of this kind (MINJUSTICIA & UNODC, 2013). In 2001, for instance, the Peace Investment Fund (FIP by its Spanish acronym) intervened 500 hectares of cocoa, while in 2002, the Peace and Development Program in Magdalena Medio established 675 hectares of cacao in San Vicente (Arrieta et al., 2012). Recently, more importance was given to the role played by the cacao sector in the development of rural areas in Colombia. In 2016, the Colombian government signed the most important peace agreement in the country's history. A core component of the peace process, “solving the problem of illicit drugs,” addresses voluntary crop substitution as one of the primary alternatives for the problem of illicit crop cultivation. In this context, the Colombian government declared cacao as a peace crop with enormous potential as a substitute for illegal coca (Swisscontact, 2016). The identification of cacao as a peace crop led to an increase in national and international efforts supporting Colombia's cacao sector development, including the recent funding of multiple projects (MADR, 2016). In such circumstances, the adoption of cacao clones and soil amendments occurred in a context where cacao farmers were the target of several social interventions.

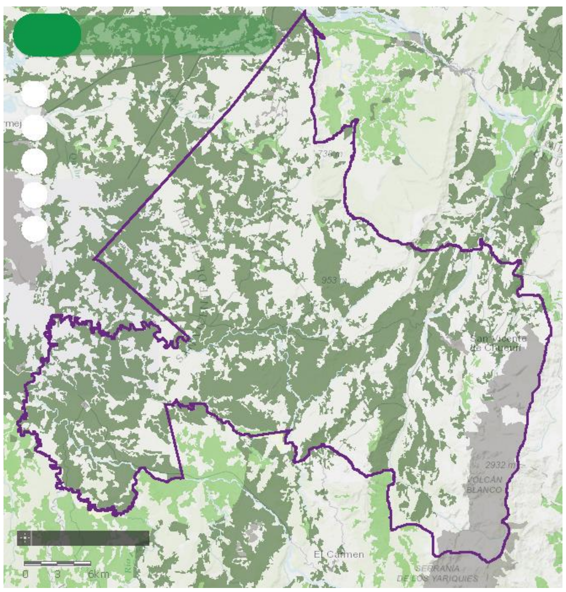
Climate

Given the physical nature of farming, farmers' decisions were also influenced by environmental factors. Accordingly, the description of the climate of the research location is relevant not only to understand how San Vicente de Chucurí became the cacao capital of Colombia but also to be aware of the environmental conditions under which farmers adopted innovations.

In San Vicente, according to the Unity of Rural Agricultural Planning (UPRA by its Spanish acronym), 45% of its almost 110,000 hectares (270,000 acres) have a high suitability for cultivating cacao (**Figure 4**). Even though suitability was established using a total of 57 variables (25 for physical criteria, 25 for socio-ecosystem criteria, and 7 for socio-economic criteria), two specific variables, rainfall, and temperature, are of note as these have significant influences on farming.

In most areas of this mountainous municipality, annual rainfall is higher than 1,800 mm (**Figure 5**), the amount of water needed by the cacao tree. While surpassing this previous threshold might well be considered an advantage for farmers, it also qualifies as a problem. From both perspectives, rainfall in San Vicente was inherently connected with farmers' behaviors, including the adoption of soil amendments and clonal cultivars. The distribution and the amount of rain on San Vicente indicates that cocoa farmers did not have to worry about finding ways to reduce drought stress. In this way, farmers did not need to use drought-tolerant varieties (Carr & Lockwood, 2011). Likewise, they did not need to implement irrigations systems (Fedecacao, 2015), a practice that influences fertilization strategies followed by farmers.

Figure 4: Cacao suitability map of San Vicente de Chucuri



Note. The dark green color indicates areas with a high suitability for cacao. Adapted from UPRA (2020).

In contrast, excessive rainfall in some areas of San Vicente became a factor that affected the incidence of diseases (Bailey et al., 2018; Deberdt et al., 2008). Of particular interest to farmers in this municipality were black pot and frosty pot rot. As participant 02 in this research highlighted, due to both diseases, farmers "could lose more than 50% of the harvest, and this is how peasants become disillusioned, and this might be why they stop cultivating cocoa or diversifying to another crop." Thus, cocoa farmers' decisions took place under the constant pressure of pathogens threatening farmers' livelihoods.

Land Use Regulations

Land use in San Vicente, essential to understanding the context in which agricultural innovations are adopted, is influenced, besides the weather, by land-use regulations. For example, in the eastern part of the municipality, where rainfall averages are lower, a colder annual temperature, rather than the rainfall, limited the development of the cacao crop (see **Figure *6***). As the optimal range of temperature for the cacao tree is between 22°C–30°C (or 72°-86°F) (Fedecacao, 2015), most of the cocoa crops were located in the central part of the municipality, at an average altitude of 700 meters above sea level. While the higher and colder eastern part of San Vicente is ideal for other crops, the 7,700 hectares Yariguíes National Park (Spanish: Serranía de los Yariguíes) limited further agricultural development (see grey areas in **Figure 4**). Indeed, it has been estimated that 84,000 hectares in San Vicente (77% of the territory) are in zones strategic for ecosystem conservation (Municipal Council SVCh, 2020). Under this circumstance, land use regulations in the cacao capital of Colombia impacted the development of other crops, such as the case of coffee, which optimal temperature range (18°C–21°C or 64°–70°F) are mostly found in such protected areas.

History: From Coffee to Cacao

Coffee has played an essential role in farmers' culture in San Vicente. Even though the area of this crop has been decreasing, the relevance of coffee cultivation on farming decisions in San Vicente is still considerable. Further, understanding the coffee dynamics in this region is essential for understanding San Vicente's current situation, including that one related to the adoption of agricultural innovations in cacao.

Figure 5: Map of Santander (left) and San Vicente de Chucuri (right) showing the average annual precipitation from 1981-2010 (Adapted from IDEAM, 2010)

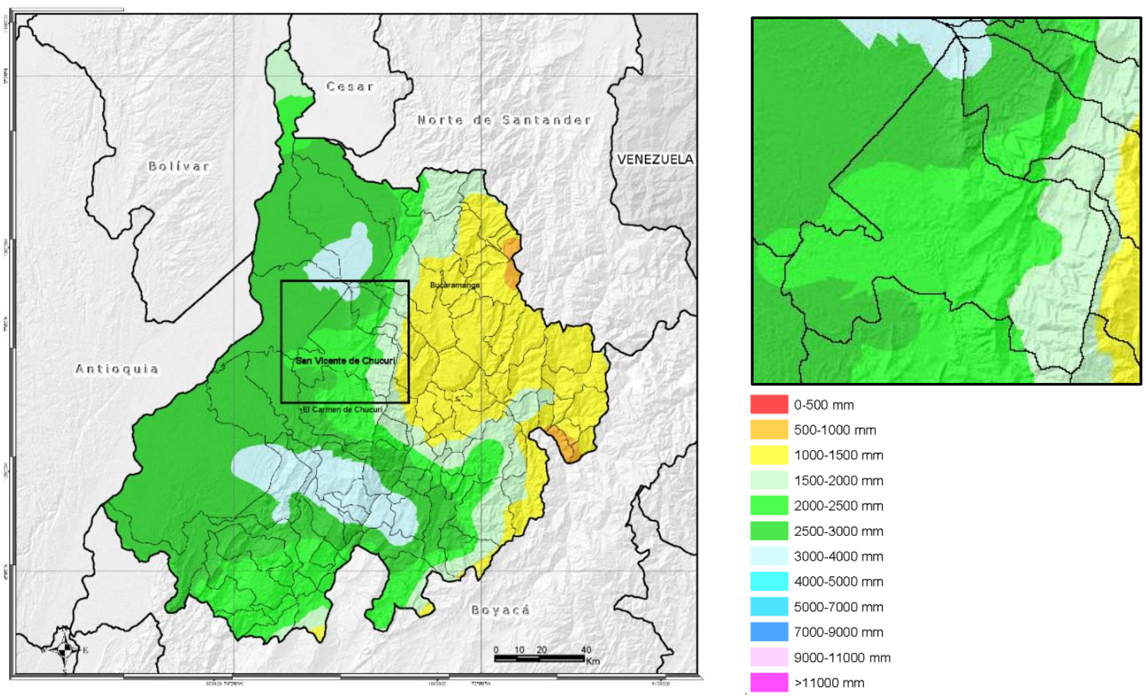
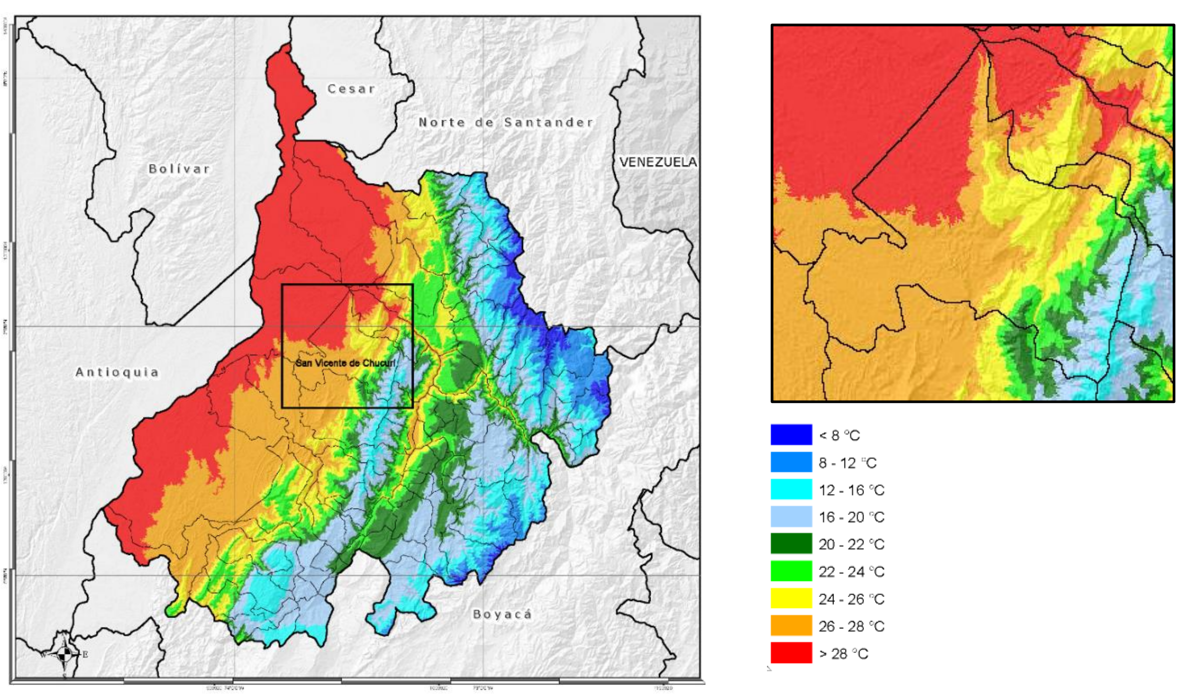


Figure 6: Map of Santander and San Vicente de Chucuri showing the average annual temperature from 1981-2010 (Adapted from IDEAM, 2010)



In San Vicente, the decline in coffee came along with the rise of cacao production. Participant 09, a coffee extensionist who worked five years in this municipality, affirmed that "San Vicente, according to the 1980 census, had between 14,000 to 16,000 hectares of coffee." Participant 09, however, recognized that the 1980 census might not have been entirely accurate as it was undertaken using aerial photography. Nonetheless, in 1996, a more reliable census suggested that San Vicente had 8,000 hectares of coffee (Participant 09). More recently, the 2014 agricultural census estimated a total of 2,400 hectares of coffee in this municipality (Cámara de Comercio de Bucaramanga, 2018). The area of cacao, in contrast to coffee, has increased. In 2001, it was reported that San Vicente had 10,259 hectares with cacao (Mojica-Pimiento & Paredes-Vega, 2006). Nowadays, according to the Municipal Council (2020), a planted area of 15,696 hectares is made of San Vicente, the Cacao Capital of Colombia.

While the establishment of the Yariguies National Park in 2005 might help explain the decline in the coffee area in San Vicente, the story would not be complete without mentioning the coffee diversification program run by the National Federation of Coffee Growers of Colombia. The diversification program started in 1963, intending to face the volatility of coffee prices, an agricultural commodity that accounted for more than half of the country's exports (Pérez Toro, 2013). Hence, the diversification program focused on promoting staple food crops and export crops other than coffee, keeping the latter industry active. An important activity to reduce the dependency on coffee was the substitution of coffee crops located in marginal areas, promoting the establishment of other crops. Among these alternative crops, cacao was prioritized due to its anticyclical price compared to coffee. As a result, the diversification program proposed, among other activities, to fund 60% of the costs of establishing 10,000 hectares of cocoa in the country (Pérez Toro, 2013). However, according to the previous author, the program was not implemented in the department of Santander until 1974.

Around the same time the diversification program began to be implemented in Santander (1974), a separate event that shaped the future of coffee in the Americas was occurring. The incident also molded the story of cacao in San Vicente de Chucuri. In 1975, winds coming from Western Africa carried the spores of the coffee leaf rust fungus into Brazil's coffee zones (McCook, 2006). Eight years later, coffee leaf rust (*Hemileia vastatrix)*, one of the most economically significant diseases of coffee, arrived in Colombia. The arrival of this disease added another argument to the coffee diversification programs, particularly in marginal zones located in warmer, lower altitudes areas where the incidence and severity of the disease were the highest, making it more expensive to control that in coffee crops in colder conditions (Belachew et al., 2020; B Sáenz & Soleibe A, 1988). Thus, as Sáenz & Soleibe A, (1987, 1988) presented it, the arrival of the coffee leaf rust in Colombia strengthened the cocoa sector by making it a potential substitute for around 300,000 hectares of coffee located in lowland fields, such as those coffee areas in San Vicente.

The influence of the coffee sector on cacao farmers in San Vicente was palpable. Besides the promotion of the cacao crop, the National Federation of Coffee Growers of Colombia (Fedecafe), through its extension service, promoted the adoption of best agricultural practices among farmers in San Vicente. According to participant 09, in 2011, six extensionists from the Federation of Coffee Growers provided advisory services to coffee farmers who, in most cases, also cultivated cacao. The service of soil analysis provided by this federation is a good illustration of how cocoa farmers benefited from this institution. In several cases, as reported by

Participant 05, soil analysis carried out through the Federation of Coffee Growers were used to take fertilization decisions for the cacao crop. Likewise, the fertilizer recommendations provided by this institution directly influenced the practices of cocoa farmers, as it is described later in this chapter in the Soil Amendments Adoption Model. Under these circumstances, the coffee sector shaped the context in which cacao farmers took agricultural decisions. Indeed, understanding the evolution of coffee farming is helpful to know how San Vicente became the cacao capital of Colombia.

Fedecacao

Being the largest cocoa producer in Colombia means that San Vicente was the largest financial donor to the National Fund for Cacao. The National Fund for Cacao, whose primary goal is to fund programs promoting the development of the cacao sector through research, technology transfer, and commercialization support, is administered by Fedecacao. This parafiscal fund, as previously described, is collected through a fee that is three percent (3%) of the selling price of each kilogram of dry cacao beans. Thus, cocoa farmers contribute to this fund every time they sell their cacao. In 2020, for instance, Colombian farmers' contribution to the fund was around USD 4 million[13], while the estimated value for San Vicente's farmers was close to USD 500,000[14].

As the funds from this fee are allocated to the regions based on their respective contributions, the role played by Fedecacao in San Vicente de Chucuri was significant. In San Vicente, for instance, several research participants stressed that Fedecacao played an essential

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[13] This value was obtained by the information of cocoa production in 2020 (63,416 tons, Table 1), the average price of cocoa in Colombia in 2020 (COP 8,000/kg, Figure 1), and an exchange rate of COP 3,700 per 1 USD.

[14] Assuming that San Vicente produced 12,44% of the cocoa in Colombia, as described by (Municipal Council SVCh, 2020)

role in providing programs and incentives that encouraged farmers to adopt agricultural innovations. As a way of illustration, participant 11 mentioned that there had been times when Fedecacao had around 80 extensionists working in San Vicente. The previous affirmation was supported by participant 09, who affirmed that when the Federation of Coffee Growers had six extensionists providing advisory services, Fedecacao had 52.

The role of Fedecacao in San Vicente went beyond providing information to farmers. For instance, in San Vicente, Fedecacao has one point of purchase where farmers could directly sell their beans. Likewise, 15 minutes away from the urban center, Fedecacao has an experimental farm where certified propagation material (seeds, seedlings, scions) was produced and distributed to farmers. Together with two laboratories in San Vicente, this farm was also fundamental to carrying out a breeding program that recently registered new clonal cultivars of cacao. Cocoa from these newly released clones was awarded in national and international[15] competitions, highlighting that San Vicente outstands in the country for the quantity and quality of its cocoa.

Farming Objectives

To understand the adoption of agricultural innovations among cacao farmers it is necessary to recognize farmers' objectives for implementing such practices. In the case of San Vicente, the adoption decisions made by cacao farmers occurred in a context in which farmers focused their efforts to increase their revenues. In this context, increasing the cocoa production

[15] See the recognition from the Cocoa of Excellence Award, in Paris http://www.cocoaofexcellence.org/the-best-50-samples-2019-edition

was a critical strategy followed by farmers to enhance their wellbeing. Participant 06, for instance, affirmed that "increasing [cocoa] production is our everyday thinking because if one increases the production, then one has more resources and one will end up living better."

Even though increasing cacao yields was reported as the primary strategy followed by farmers to increase revenues, farmers also recognized the importance of altering the second impacting revenue: the price of cocoa. Hence, farmers reported diverse strategies to gain access to a market that could pay a higher price for their cacao. Participant 03, for instance, said that one of his "short-term goals is to organize a small group of farmers and standardize our practices to enhance the quality [of the cacao beans] …organize ourselves to focus on quality that allows us to seek new markets."

Besides increasing cacao yields and enhancing the quality of the beans, farmers also followed crop diversification strategies to increase revenues. This approach was primarily implemented by farmers in the earlier stages of the cacao, as participant 02 affirmed,

> When we talk about cacao, we are talk about a long-term crop that begins to be profitable four years after being established. In contrast, with the plantain, one harvests it when it is 15-18 months old, generating the resources needed to take the [cacao] areas to a production stage.

Participants also reported that in addition to increasing revenues, land-use decisions were made by farmers to accomplish two additional working objectives: stabilizing incomes and maintaining food security. Farmers' desire to enhance the stability of their income in the short and long term influenced the implementation of crop diversification. Participant 03, for instance, said that “In addition to citrus-fruit cultivation, I cultivate banana and plantain as secondary crops that allow me to have an alternative income source.” Despite the fact that the Municipal Council (2020) recognizes an area reduction of annual crops in San Vicente, the research subjects reflected the importance of mixing the cacao crop with annual food crops to enhance their food security. As a result, participants indicated that their farms also produce plantain, cassava, avocado, limes, oranges, among others food crops.

Social Issues

So far, it has been described how the cocoa market, as well as the quality attributes of the beans have created a particular context in which farmers' behaviors happened. It has also been shown how the natural environment and human decisions and institutions have shaped the history of cacao cultivation in San Vicente. Next, it is described how social issues shaped the context where cocoa farmers adopt innovations.

Cacao in Colombia is produced by around 65,000 small-scale producers in 30 out of the country’s 32 departments (equivalent to U.S states) (Baquero, 2018; MADR, 2020). Santander, the largest producer department, contributed 41% of the country's production in 2020 (Fedecacao, 2021). Within Santander, small farmers from San Vicente de Chucuri were responsible for 30% of the cacao production.

In 2020, San Vicente had a population of 33,593, among which 62% were rural (Municipal Council, 2020). As in many other Colombian regions, it has been acknowledged by government agencies that the social issues of the rural population in San Vicente were more acute than those of its urban neighbors. In 2018, according to the National Administrative

Department of Statistics (DANE), the multidimensional[16] poverty of San Vicente[17] was 45% for the rural area and 19% for the urban district (DANE, 2018). The unsatisfied basic needs criteria also indicated that some of the most disadvantaged citizens in San Vicente live in rural areas. According to the Municipal Council (2020), basic needs were not met in 32% of rural households, compared to 6% in the municipal seat. In the same way, 23% of rural citizens faced housing needs, compared to 2% of the people living in the town center. The urban/rural gaps in education were also evident in San Vicente. Illiteracy was higher among the rural population (18%) than its urban counterpart (9%). The same occurred in educational attainment, school absenteeism, and educational lagging (Municipal Council SVCh, 2020).

Small farmers in Colombia also faced issues accessing land. Indeed, access to land in Colombia has been a problem since colonial times (Machado, 2017). The country also possesses challenges in land demarcation, a high concentration of land ownership, and the under-exploitation of arable land (OECD, 2020). Likewise, the government doesn't control the entire territory, and it hasn't resolved the land conflicts (Machado, 2017). According to the latest 2014 agricultural census, 72% of the farmers declared land ownership (DANE, 2016). However, according to the Rural Agricultural Planning Unit (UPRA), 54% of the farm units in Colombia held informality in land ownership. The Colombian cacao sector does not escape from this situation. In two central cocoa-producing municipalities, San Vicente and El Carmen de Chucuri, the informality in land ownership in 2020 was 21% and 54%, respectively (Neva & Prada, 2020).

[16] The dimensions considered are (1) education ,(2) the childhood conditions, (3) employment, (4) health, and (5) access to public services and housing situation.
[17] For the same year, the multidimensional poverty of Colombia was 39% for the rural area and 13% for the urban.

The land tenure system adopted in San Vicente also reflected social relationships regarding rights to land that also influenced the adoption of agricultural innovations. Participant 01 described how the relationship between the landowner and the farm inhabitant's[18] worked,

> For example, I have a cacao farm, and I decide to go to live in the urban center because the farm has allowed me to get the money to have a house there. When I go to the town center, I leave my house [on the farm] to the inhabitant, and he receives it in an agreement. The conditions are the next. He [the inhabitant] does all the farm labor, and I help him with the fertilizer that he applies to the plants, which is done two times a year. Thus, I pay for the fertilizers, and he provides the workforce required to apply them. Another thing that goes half and half is the pruning, which occurs twice a year. In this case, he provides the food for the individuals pruning, and I pay them. When cocoa is sold, if 1,000 kilograms of cocoa are sold, 500 kilograms are for the landowner and 500 kilograms for the inhabitant.

Labor constraints were also a constant for cacao farmers in Colombia, including those from San Vicente. While family labor is usually employed for disease controls and fertilization, there are cases when hiring labor is needed, especially for harvesting, pruning, and controlling weeds (Abbott et al., 2018). In the last years, it has been reported that cacao farmers in San Vicente faced difficulties finding labor (TechnoServe & ANDI, 2015). Even though this municipality has a large working-age population (86%), high migration rates of rural youth to urban centers increased the labor shortage (Municipal Council SVCh, 2020). While Colombia

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[18] Inhabitant is the translation used here to the Spanish word "viviente."

does not face child labor issues in the cacao sector, the informality of the rural worker was another matter of concern. Information from DANE (2018) indicates that more than 80% of the workforce in rural areas worked under conditions of informality. For the case of San Vicente, the level of informality was 85% (Municipal Council SVCh, 2020).

The Cacao Clones Adoption Model

Specific Context

The set of conditions affecting the adoption of innovations varied according to the innovation. There are cases in which a group of structural conditions directly influenced the adoption of specific innovations. However, in other cases, the same conditions did not affect how the innovation is adopted. Therefore, while the previous overall context is necessary to understand the general adoption of innovations among the cacao farmers, it falls short of describing more specific conditions influencing the adoption of unique technologies. In this way, although both innovations approached in this research shared a common context, it is imperative to describe the particular context in which they diffused. The specific conditions described next constitute the context in which clonal cultivars of cacao were adopted.

Length of cacao breeding programs

Creating the varieties that cacao farmers adopt is a complex and long-term process. Cacao is a long-lived tree that can be cultivated for more than 40 years (Jagoret et al., 2011). Although a cacao tree can begin production 18 months after being planted (Almeida & Valle, 2007), the trees might take approximately six years to achieve their full potential (Tahi et al., 2019). As a result, breeding programs can take several years before a new cacao variety is available to farmers. A good illustration is the cacao breeding program at the Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica (Phillips Mora et al., 2013). Before CATIE could release six novel cacao varieties available for farmers, researchers had to collect data for 11 consecutive years. All these years were necessary to confirm that the new varieties had the traits in which the plant breeders were interested, particularly bean yield and disease resistance, which have received the most attention from cacao breeders (Lopes et al., 2011).

Insights into the strategies used by cacao breeders are relevant to understanding the complexity of making these innovations available to farmers. In the case of cacao, plant breeders rely on different strategies to create new varieties. Cacao breeding programs, then, can use one or more of these strategies. Under those circumstances, the number of approaches and the time needed to create new cacao varieties vary. By way of illustration, it will be described the strategies used by plant breeders in Brazil, Central America, and Colombia.

Collecting and conserving germplasm banks has been a central strategy in cacao breeding programs. The collection of cacao varieties has been of great importance for plant breeders due to one main reason: the great diversity of already existing varieties of cacao (Motamayor et al., 2008). This great diversity of cacao means that the ideal cacao variety or, the ideal trait- that the plant breeder is looking for-or might look for in the future, is already out there. Working under this logic, cacao breeding programs in Colombia (Rodriguez-Medina et al., 2019), in Brazil (Lopes et al., 2011), and Central America (Phillips Mora et al., 2013) have begun by collecting and maintaining a diverse array of plants, to which they refer to as the germplasm banks. What is interesting, however, is that the cacao seeds cannot be stored for more than a couple of weeks

(Lahay et al., 2018). As a result, germplasm banks of cacao are primarily composed of plants, making the conservation process more resource-demanding.

The results of collecting and conserving cacao germplasm are reflected in the scale of the banks of diverse research institutes. In Colombia, the Colombian Agricultural Research Corporation (Agrosavia) currently has about 500 accessions[19] in each of the two germplasm collections established in the country (Rodriguez-Medina et al., 2019). In the Brazilian state of Bahia, the breeding program at the Cocoa Research Center (CEPEC/CEPLAC) has a total of 1,300 accessions (Lopes et al., 2011), while in CATIE, in Costa Rica, there are about 1,100 of them (Phillips Mora et al., 2013). These germplasm banks' size may indicate that no new collections are needed. Indeed, some scientists agree that breeding programs have relied upon a few cacao genotypes, missing the wide diversity available in the germplasm banks (Lopes et al., 2011; Phillips Mora et al., 2013). While this might be true, the importance of increasing the genetic diversity is still recognized, which is palpable in recent germplasm collections carried out in Colombia (Rodriguez-Medina et al., 2019).

Once the cacao germplasm has been collected, plant breeders can use several strategies to obtain new cacao varieties. The complexity of the strategies used by plant breeders and the time in which a new cacao cultivar is obtained vary a lot. In some cases, plant breeders take comprehensive approaches, such as in the case of recurrent selection. Recurrent selection consists of a cyclic breeding method in which genes of interest are accumulated in cacao trees used as parents in the

[19] "An accession is a group of related plant material from a single species which is collected at one time from a specific location" https://opgc.osu.edu/

breeding program (Rodriguez-Medina et al., 2019). Despite its potential, this breeding strategy is more complex and can take longer than other strategies more commonly utilized. In recent years, the advancement of molecular biology has come along with the development of tools that can support conventional breeding programs. As an illustration, publications of the cacao genome sequence (i.e., Argout et al., 2011) have allowed plant breeders to identify candidate genes that may be affecting traits of interest, such as plant defense against pests and diseases, bean quality characteristics, yield, or even the accumulation of heavy metals. Under these circumstances, molecular plant breeding has become a common practice for crop improvement.

Perhaps the ‘fastest’ route to create a new cacao cultivar is to identify and select the most promising accessions from the germplasm bank and then, based on clonal trails, evaluate and liberate the new cultivars. This strategy is called mass selection. To breed a new cultivar using mass selection, plant breeders conduct experiments in which the trees of interest are compared with an already released cultivar. The duration of these experiments may take several years as plant breeders must collect enough data before the new variety can be liberated to farmers. When trials are conducted on a larger scale, particularly in several locations, Lopes et al. (2011) reported that this process could take seven to ten years, which is consistent with the duration reported by Phillips Mora et al. (2013) in CATIE. In addition to selecting accessions from germplasm banks, researchers can also choose promising trees in local plantations. This has been an important strategy implemented by cacao breeding programs in Colombia. This method consists of that, instead of selecting the plants from a germplasm bank, the plant breeder characterizes individual trees wherever they are located, usually in local cacao farms. Then, based on the characterization, the trees with traits of interest are collected and evaluated in experimental trials, as previously described. As a result of this mass selection in local plantations, outstanding cacao varieties have been released to cacao farmers in Colombia in the last ten years (Rodriguez-Medina et al., 2019). Examples of these cultivars bred in Colombia are described in **Table 5**.

Table 5: Characteristics of cacao cultivars bred in Colombia

Cultivar	Yield (kg/ha/year)	Dry bean weight (g)	Pod Index*	Frosty Pod Reaction**	Sexual Compatibility
TCS01	3,300	3.0	9	S	SC
CNCh12	2,876	1.7	17	MR	SC
CNCh13	2,310	1.7	13	MR	SC
TCS06	2,000	2.0	12	R	SI
FLE3	1,843	1.5	17	MR	SI
FSA13	1,824	1.5	24	MS	SI
FEAR5	1,689	1.4	17	MS	SC
FLE2	1,612	1.7	13	MR	SI
FSA12	1,575	1.3	18	MR	SI
FSV41	1,496	2.0	13	S	SC
FTA2	1,389	1.6	15	MS	SC
FEC2	1,370	1.3	16	R	SI
FGI4	1,255	1.6	18	MS	SC
FMA7	1,138	1.5	12	-	-
SCC61	1,090	2.0	14	S	SI
CAU39	918	1.0	24	R	SI
FSV25	905	1.6	14	-	SI
FYC2	635	2.1	15	-	-
FSV155	450	1.5	25	MS	SC
CCN51	1,900	1.5	15	MR	SC

Note. *Pod index is the number of pods needed to produce one kilogram of dry cocoa beans. **Frosty pod reaction: Susceptible (S); Moderately susceptible (MS) Moderately resistant (MR); Resistant (R). Sexual compatibility: Self-compatible (SC); Self-incompatible (SI). *** The clone CCN51 was not bred in Colombia. It is included in this table as this clone is used as a control in breeding programs (Phillips Mora et al., 2013). The information of the table was obtained in AGROSAVIA (2019a, 2019b); ICA (2020a, 2020b); Perea et al. (2013).

Breeding low-cadmium accumulation cultivars

Creating low accumulating cadmium (Cd) cacao varieties adds extra complexity to an already challenging endeavor. This complexity would possibly account for the fact that cacao farmers do not yet have access to a low-cadmium accumulation cacao cultivar. The main reasons that might explain this difficulty have to do with the nature of the cadmium problem, particularly its novelty and intricacy.

In contrast to productivity traits (i.e., number of pods per tree, number of beans per pod, the weight of beans), Cd traits are not visible to the human eye. This observability issue indicates that plant breeders must rely on extra equipment, affecting the cost and the amount of data collected. Likewise, breeding programs for Cd should be conducted in regions with high Cd contents, narrowing the possibility to use already established experimental farms. While it would be possible to establish experiments under controlled conditions, the costs of doing this will be higher, and field experiments would still be needed. Also, conducting research on Cd in grafted plants might be problematic as the Cd uptake by plants might be influenced either by the rootstock (underground part), the scion (plant's shoots) or by their potential interaction (Engbersen et al., 2019).

Equally important is the novelty of this challenge. Cd is a relatively new issue for the cacao sector, especially if we compare it with other traits that cacao breeders have addressed for almost one century (Rodriguez-Medina et al., 2019). The previous indicates that our understanding of the connections between Cd and the cacao tree is much lower than our knowledge about other cacao tree factors. For instance, it is already known that the chemical compound clovamide is a resistance factor against a specific pathogen in cacao (Knollenberg et al., 2020). The previous indicates that plant breeders can identify and introduce the genes responsible for clovamide production into cacao breeding programs to tackle such pathogens. By contrast, this type of information is not currently available for Cd. For instance, researchers have compared Cd absorption in a wide diversity of cacao accessions (i.e., Lewis et al., 2018). They have demonstrated that cacao varieties differ in their efficiency of Cd sequestration (R. E. T. Moore et al., 2020). However, the mechanisms for the differences in Cd accumulation remain unclear.

Diversity of cacao cultivars in Colombia

Cacao farmers in San Vicente could choose from a vast array of cacao cultivars, each offering a different set of traits, as indicated in **Table 5**. Further, farmers could pick between cacao cultivars bred in Colombia and those introduced from other countries, such as the Imperial College Selection (ICS) and the Trinidad Selected Hybrids (TSH), among others.

Propagation methodologies

Once cacao clones have been bred using the strategies previously described, there are several ways to propagate them. Current techniques used to propagate cacao include seed propagation, conventional vegetative propagation, and tissue culture. Seed propagation, the cheapest of all propagation methods, doesn’t ensure the desired genetics of the parent are inherited into its progeny. In contrast, tissue culture generates genetically uniform plants, a characteristic wanted by farmers. However, even though specific techniques such as cacao somatic embryogenesis have been well documented, this method requires expensive sterile laboratories (Sena Gomes et al., 2015). In this way, cacao is typically propagated through conventional vegetative propagation, particularly by using methods such as grafting and rooted cuttings. The reason for this is that, in addition to perpetuating traits of interest, these methods are simple to implement.

In the early 2000s, hybrid seed (from now on hybrids) was the planting material utilized to establish cacao plantations in Colombia (Perea et al., 2013). Nowadays, grafting[20] is the preferred method of vegetative propagation of cacao. In Ecuador, however, rooted cutting is a popular method of propagation (Sodré & Gomes, 2019). The main difference between grafting and rooted cuttings is that a grafted plant requires a rootstock, a different plant providing the rooting system onto which the desired cultivar is grafted. While both techniques ensure the propagated plants are identical to the parent plant, grafting permits root and shoot traits to be selected independently rather than requiring both sets of traits to be present in a single genetic individual (Warschefsky et al., 2016). Under these circumstances, rootstocks are a strategy to deal with soil-related issues, such as soil pathogens and abiotic stresses such as heavy metals (Rivero, Ruiz, & Romero, 2003). The previous principle has been helpful to enhance the performance of diverse crops such as avocado (Beyer et al., 2021) and tomato (Rivero, Ruiz, Sánchez, et al., 2003). Consequently, the diffusion of grafting as propagation methodology in Colombia implies that cacao farmers' decisions involve the selection of the grafted cultivar and the variety utilized as a rootstock.

In cacao, rootstocks seedlings are obtained through open-pollinated seeds usually established in cacao nurseries. In only a few cases, farmers plant rootstock seeds directly on the

[20] This document includes budding as a grafting technique

ground, a practice traditionally carried out that is no longer recommended (Sena Gomes et al., 2015). Even participant 14, the only participant who reported to have sown the seed directly at their final growing positions, recognized that *"it is very rare who does it*." Thus, seedling rootstocks in Colombia are usually sown in plastic bags in a greenhouse facility. In this way, most cacao farmers in San Vicente who adopted clonal cultivars did so by utilizing rootstock seedlings produced in nurseries.

Uniformity of rootstocks materials

In Colombia, the production, distribution, and commercialization of rootstocks and other cacao planting material are regulated by the Colombian Agricultural Institute (ICA) through resolution 3434 (Resolución No. 003434, 2005). While ICA recognizes the importance of the uniformity of the planting material, the regulations under which rootstock seedlings are produced don't reflect so. This previous argument is supported by the levels of variability of seed-propagated populations used to obtain the rootstocks. As an illustration, resolution 3434 indicates that "when farmers don't have access to rootstock seedlings from authorized clones, farmers can use seeds from hybrid plantation trees with a clear phenotype of the clone IMC 67." Even though IMC67 is a clone widely recommended as a rootstock (Isele et al., 2020), a myriad of genetically diverse rootstock seedlings could be obtained by following the previous recommendation provided by the ICA.

Additionally, even if farmers have access to seedlings from the clone IMC 67, the self-incompatibility characteristic of this cultivar indicates that this clone must be pollinated by another cultivar, increasing the diversity of the produced seeds. The previous incompatibility trait is also shared by the cacao cultivars[21] recommended as rootstocks by Article 2 of the Agreement 003 from the Colombian National Cacao Council (Bernardo Sáenz, 2010). In this way, despite current regulations to propagate rootstock materials in Colombia, cacao farmers from San Vicente usually planted disparate rootstock materials.

Focus on the scion, not the rootstock

In San Vicente, farmers' decisions regarding the planting material focused on the aerial part of the plant, not on the rootstock. Some of the participants' comments evidenced the lack of clarity on the rootstock utilized to establish cacao plantations in this municipality. Participant 06, for instance, described the way he obtained seeds used as the rootstock, a process also reported by participants 18 and 20:

> One could get the seeds from any [tree] because one knows that once the seedling is eight months old, one will graft it, and then is when one takes the clone from the desired plant. There is no mystery while looking for seed.

The previous situation in which farmers got the seeds from their farms was not the rule in San Vicente. Indeed, some of these participants also affirmed that they had bought seedlings at commercial nurseries. Still, the previous comment from participant 06 illustrated how farmers concentrated their efforts on selecting the cacao cultivar conforming the upper part of the plant (the scion) rather than the rootstock (the root system).

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[21] The cultivars recommended are P7, PA46, PA150, and PA121.

The focus on the grafted cultivar was also evident across breeding programs and, in general, across scientific publications. Breeding rootstock for cacao is by far less common than scion breeding. For instance, all the previously described breeding programs seek desirable traits of the aerial part of the plant (i.e., disease resistance of pods, number of pods per tree, bean size), leaving aside characteristics concerned with the root system. Even a recent paper from Rodriguez-Medina et al. (2019) describing the history of cacao breeding in Colombia doesn't refer to efforts to develop improved rootstocks varieties, which is consistent with the absence of reports regarding breeding programs for rootstocks in cacao. Regarding the research supporting the use of grafting in cacao, the work by Palencia et al. (2007) has been used to support the recommendations of the cacao cultivars used as rootstocks. More recently, and mainly due to the cadmium issue, the scientific literature on rootstocks in cacao has increased (i.e., (Fernández-Paz et al., 2021). In this way, despite the long time during which rootstocks have been utilized in the propagation of cacao, the advantages of grafting cacao are not as evident as for other species (Sena Gomes et al., 2015), which supports the idea that the in the cacao sector, the focus on the selection of cultivars is on the scion, not the rootstock.

Buying seedlings rather than doing nurseries in the farms

Knowing farmers' preferences on how to get planting material is also relevant to understanding the selection of the cacao varieties used by farmers. In San Vicente, cacao farmers tended to go to commercial nurseries rather than doing the nurseries at their locations. Although it was just discussed that some participants had obtained the seeds from their farms, the previous was not the case for most farmers. Indeed, some participants affirmed that most cacao farmers in San Vicente preferred to buy the seedlings in one of the 8-10 commercial nurseries in this municipality. As described by participant 15 next, the rationale for such preference was the cost-benefit of getting seedlings from the nurseryman.

> When one makes the nursery, one doesn't know what to are the inputs needed. But then you realize that when it is not the cricket that damages the plants, the plants get damaged. Therefore, I prefer to buy the seedlings [at the nursery] and plant them.

In the same way, participant 01, a cocoa farmer who also manages a cacao nursery in San Vicente, explained why farmers in San Vicente prefer to buy the seedlings rather than doing them at their farms,

> Farmers don't do it [nurseries] and come to me to buy the plants for the following reason. If farmers make a nursery of 1,000 seedlings, the average amount of seedlings that folks buy, then farmers will have a minimal investment. So, in cacao, when one establishes a nursery, one must follow a set of agricultural practices. One has to fertilize, to apply fungicides and pesticides. Now, the commercial nurseryman has an investment of around 200 million [Colombian] pesos, so this person cannot ignore these agricultural practices because if the 200 million are lost, the nurseryman goes bankrupt. In contrast, the farmer's investment for 1,000 seedlings is around 300,000 pesos …Additionally, the farmer has to invest [in the structure of the nursery], and the farmer is not going to need it any longer; therefore, it is cheaper to buy the rootstock seedlings from in the commercial nursery.

Under these circumstances, farmers' decisions to buy the plants, rather than making the nurseries at their locations, matter, as the decision of the cultivar used to get the seeds rested with the nurseryman.

Grafting in the field

Once farmers have decided to propagate a desired cultivar of cacao, several grafting techniques can be used. Based on where the grafting process occurs, the grafting techniques can be classified into two [22] broad groups, 1) grafting in the nursery and 2) grafting in the field. In many regions in Colombia, cacao is grafted in the nurseries. As an illustration, the ongoing project "Nurseries for Peace," with a capacity to produce two million plants yearly, delivers farmers plants grafted in nurseries (Grupo Nutresa, 2018). In other circumstances, however, farmers prefer to graft cacao on its definitive site.

In San Vicente, cacao farmers grafted the plants on the field rather than buying grafted plants from nurseries. In other words, San Vicente's farmers preferred to buy rootstock seedlings from the nurseries rather than buying grafted seedlings. According to the research subjects, several reasons explain such behavior. In the first place, as participant 14 indicated, "grafted seedlings are produced in small nursery plastic bags where the plants must stay five to six months before planting. Therefore, the taproot could get damaged." The previous argument was also mentioned by participant 13, who affirmed that in some projects he participated in, the seedlings stayed in the plastic bags more time than planned, which affected the development of

[22] The classification of grafting methods based on where the process takes place is commonly used in Colombia (i.e., Fedecacao, 2015). However, other classifications of grafting methods are used (i.e., Sena Gomes et al., 2015)

the plants. In this regard, participant 13 affirmed that "even ten years after were planted, one can find plants on the farms that are one meter tall, plants that didn't grow." Although the blame for such delays could have been either the project, the nurseryman, or even the farmer, the conclusion was that "farmers got the idea that grafted seedlings don't work." The second reason that support participant 14's preferences for grafting cacao in the field had to do with the architecture of the plant and its implications on disease resistance,

> As the rootstock seedling is a small plant, they [nurseryman] graft [the scion] on the low part [of the rootstock seedling]. When you establish that plant, the scion will be located almost at the terrain level. In contrast, if you sow the rootstock seedling in the field, as I did it, then you graft the plant 40-50 cm above the ground. If the graft point is in the lower part, the clones would be more susceptible to diseases; that is what the rootstock is used for, to increase the disease resistance on the trunk.

In addition to the previous arguments, participants also expressed their preference for grafting in the field because plants proved more precocious. The precocity of this type of grafting enabled farmers to benefit from the earlier realization of revenues, as participant 20 mentioned,

> It is way faster, more effective, more everything when one graft in the field. Yes, because when the seedling is already grafted [in the nursery], it has been for a long time in the nursery bag. As an illustration, I had sowed some plants [grafted] before sowing other plants that I grafted by myself in the field, and those plants that I grafted are bigger and are now producing more. In other words, it works much better when grafting the plants in the field.

The negative attitude towards using grafted plants was also explained from an economic point of view. Participant 01, who owned a cacao nursery in San Vicente, explained their rationale for recommending farmers to graft in the field:

> I recommend farmers buy rootstocks seedlings and then graft them. Why? Because here in Colombia, there are frequently changing weather conditions, if someone takes the cocoa seedlings and if there is a lot of rain, a farmer could lose half of the plants. Thus, if half of the plants died, the farmer lost half of the plants worth $550 [COP] (around 40 cents), not half of the plants worth $1,500 [the price of a grafted seedling]. Then, when you hire someone grafting the plants in the field, that costs you around $500-$600. However, you are on the safe side because you only pay for the successfully grafted plants. In this way, the total cost of a grafted plant would be $550 plus $500-$600, which is around $1,100, and not $1,500, and you are on the safe side; you are not risking the $1,500 worth of the grafted seedling.

However, there was a case where a participant expressed his preference for utilizing grafted seedlings. For participant 05, the decision to establish grafted seedlings was because "even though it could be more expensive, in the end, one has a more homogenous crop."

Besides the economic rationale, workforce availability in San Vicente was also highlighted as a factor favoring the practice of grafting in the field. The grafting process requires specific skills beyond those needed for farming; therefore, farmers' decisions to not get grafted seedlings indicated the producers had access to the resources necessary to graft the plants in the field. Participant 13, for instance, suggested that farmers in San Vicente might decide to graft in the field because they were in a location where finding someone who has grafting skills was more accessible compared to other regions of the country.

Grafting in the field was also used by farmers who wanted to replace the canopy of undesirable cacao cultivars. So far, the discussion about grafting in the field has focused on those cases where farmers established first the rootstock seedling and then, once the rootstock was well developed, grafted it on its definitive site. However, there were situations where farmers grafted already established trees that were usually less than twenty years old. By doing this, farmers could increase production by replacing the canopy of undesirable trees. In San Vicente, this method is called "malayo"; however, Sena Gomes et al. (2015) refer to it as “crown grafting.”

In any case, the culture in San Vicente of buying rootstock seedlings and grafting them in the field influenced farmers' decisions on what cacao materials to propagate. By not being limited in the use of the clonal cultivars offered by the nurseryman, farmers' options regarding what cultivar to propagate were numerous. Further, farmers could use their plantations to obtain scions from the plants they would like to reproduce. For instance, participant 19 indicated that "one looks for a plant with good production and with good bean quality. One can then propagate such plant on the farm." The plants selected by the farmers were also promising trees that have not been released nor registered. In this regard, participant 06 affirmed that the cacao he grafted was obtained "from the same [trees] that are already on the farm, or even criollo cacaos that one knows that are good. If one doesn't want to extinguish such breed, one can use those plants." In this way, the propagation method adopted by farmers was relevant to understanding the cacao cultivars used by cacao producers.

Adoption of Clonal Cacao

Clonal cacao was a widespread innovation across the interviewed farmers (Table 1). In all but one of the participants' farms, clonal cultivars of cacao were part of their tree inventory. However, having adopted clonal cacao did not mean that farmers also had hybrid plants in their tree inventories. In this way, the degree to which farmers adopted clonal cacao differed across participants. There were situations where participants reported having almost all their plants grafted with a cultivar developed by plant breeders. Participant 05, for instance, affirmed that "at least 95% of the farm is renovated [with clones]." In other cases, however, the number of hybrid trees was considerable, such as it occurred with participant 19, who indicated that approximately half of the cacao area was made up of hybrid trees.

The concepts influencing the adoption of clonal cacao in San Vicente are depicted in Figure 1. The factors found to directly influence the adoption of cacao clones were grouped into three categories: 1) Donations, 2) beliefs of using cacao clones on farming objectives, and 3) personality traits. A fourth factor, farmers' perceived need to control cadmium, was included in the CCAM. Despite its irrelevance to explain the adoption of clonal cacao (reason for using dashed lines), this fourth factor was integrated into the model to approach the question that asks how cadmium influences the adoption of this innovation. Concepts found to influence the first two categories were also described in the diagram summarizing the CCAM. Figure 1 also shows how access to resources moderates the relationship between farmers' beliefs and the adoption of cacao cultivars. Next, the influence of each concept on the adoption of clonal cultivars is presented. The order in which they are described does not imply a ranking in their importance.

Donations

According to some research participants, a factor that explained why farmers have adopted clonal cacao was the donations they have received. Donations were given to farmers to encourage behavioral change. In the case of clonal cacao, the type of donations received from participants varied. In some situations, farmers received inputs, particularly seeds, scion wood, or seedling. In other cases, it was reported that they received workforce support, especially from personnel who grafted the plants.

Donations and Access to Projects

Cacao projects played a vital role in the rural development of San Vicente, as previously discussed in the overall context section. Giving donations to farmers was a strategy implemented by projects in this municipality to bring about desired changes, including the modernization of the cacao sector. In this way, as participant 06 commented, donations encouraging the adoption of clonal cacao came from several diverse projects.

> The first parcel of land that I sowed, I did with CCN51, ICS95, and SCC. Those were the first three [cacao] clones established here on the farm with a project. Because I belong to a cooperative I have always worked with, we received benefits from the Peace and Development Program in Magdalena Medio program… Later, the last thing we did was establish the clones ICS1 and ICS6 with Agrosavia, the former Corpoica. They gave us these clones that they have certified as excellent clones.

In the last two decades, cacao projects were an important donor of planting material to farmers in San Vicente. Participant 13, for instance, reiterated that the influence of projects explains a significant percentage of the clonal cultivars adopted in San Vicente. According to them, only "15% of the farmers in San Vicente have done it [adopted clonal cacao] by their initiative." The previous affirmation was confirmed during the member checking phase by participant 01, who affirmed that the adoption of cacao clones due to donations "is the most common here in San Vicente and Colombia." Likewise, the donation of planting material to farmers through projects has a long history in San Vicente. In the early 2000s, the Peace Investment Fund and the Peace and Development Program in Magdalena Medio were donating farmers planting material of clonal cacao. Twenty years later, as participant 19 described it, the influence of projects on such regards was still evident,

> This year [2021], through the municipal administration, one received calls asking if one had the space to sow 200 seedlings of cacao and an area [of the farm] that needed to be renovated through grafting so they also could help us. They pruned us one hectare of cacao; they gave us 300 grafted seedlings.

Donations and Access to Projects and Membership in an Organization

Being a member of a farmers' organization was helpful to have access to the projects that provided technical assistance and donated planting material in San Vicente. This situation was the case of participant 06 previously described. It was also the situation of participant 20, who affirmed that "<name of the organization> gave us a project for grafting; even the plants that <name of the organization> grafted are now producing cocoa." While Membership in any farmers' organization has been a prerequisite to apply to several aid programs in Colombia (i.e., MADR, 2015), donations to cacao farmers in San Vicente were not necessarily connected to associated farmers benefited by a program. In this municipality, the donations that influenced the adoption of clonal cacao have also originated from institutions providing agricultural extension and advisory services (AEAS).

Access to Agricultural Extension and Advisory Services (AEAS)

Donations and Access to AEAS

In San Vicente, the role of Agricultural Extension and Advisory Services (AEAS) went beyond the mere process of sharing helpful information with farmers. As reported by some participants, Fedecacao, the largest provider of AEAS in this municipality, also played a key role in donating the planting material and the workforce needed to establish clonal cacao.

> The seeds were given to us by Fedecacao…Thank God, Fedecacao has helped us a lot because, in any way, it supported us with [donations of] seedlings. They also gave us grafted seedlings. Also, someone from Fedecacao came and grafted a lot of plants. This person was the one who taught me how to do it, so I already started to graft. (Participant 20).

While farmers who received donations through a project were more likely to be involved in an organization, the same was not the case for those who received donations from Fedecacao. Although there were situations where the donations and extension services from programs were channeled through Fedecacao, there were also cases where this AEAS provider offered its services to anyone who needed it; as participant 11 affirmed,

> In the case of Fedecacao, which is the most significant [outreach institution] in the region, there is no distinction between affiliated or not affiliated [farmers to an organization] …at the end, if someone needs it, if there are questions or concerns, Fedecacao goes there, checks the situation, and provides a recommendation.

Beliefs of Using Cacao Clones on Farming Objectives

Participants talked about three beliefs they hold about clonal cacao. These were beliefs of using cacao clones on 1) productivity, 2) facilitating labors, and 3) improving cocoa beans quality. In this manner, participants discussed how such beliefs influenced the adoption of clonal cacao (the target innovation) or cacao hybrids, its precursor.

Beliefs of Using Cacao Clones on Productivity

Participants who adopted clonal cacao reflected their confidence in using this technology to increase the productivity of their farms. This belief was held by most participants, who indicated that the cacao clones are more productive than their precursors. Participant 15, for example, explained,

> To me, the grafted [cacao] is better; there is nothing more to say… one can see they [clones] produce more and that their beans are wider and larger [than beans from hybrids], and when you open the pod of the grafted [cacao] it is packed with cacao. In contrast, the other [hybrid] has only a few beans, and that's it. Just by looking at the pile

> [of pods]; the pile [with clones], one gets some cacao even if it is small. On the other hand, with the other one [hybrid], you can have a big pile, but in the end, you won't get anything, only husk [from the cacao pod].

The participants highlighted the homogeneity of the production of a clonal cacao plantation as an essential trait of clonal cacao. As an illustration, participant 06 commented that "in one hectare of [hybrid] cacao there could be 700 plants that were productive and 300 that were not, but with clones, all of them are productive, that's the truth." In this way, participants recognized that clonal trees are more consistent in their production and more efficient as, compared to hybrids, fewer pods are needed to produce the same amount of dry cocoa beans.

However, there were cases where participants were not confident that using clonal cacao was strategic to enhance productivity. Such beliefs then become essential to understanding the adoption of hybrid trees instead of clonal cacao. Participant 17, for instance, indicated,

> Our neighbor's farm follows Fedecacao's recommendations; it only has [cacao] clones, and that is a farm that doesn't produce as much as ours…one can see in our farm [hybrid] trees with 50-60 pods while in other farms one sees grafted trees with 10-15 pods.

Participants recognized, however, that the number of pods per tree could be misleading. In this regard, even though **Table 5** doesn't show information on cacao hybrids, it provides a good illustration of this situation. According to **Table 5**, a farmer would need to harvest 24 pods of the clone CAU39 to produce one kilogram of dry cacao beans; in contrast, the farmer only needs to harvest nine pods with the clone TCS01 to obtain the same amount of cocoa beans.

Nonetheless, despite the confounding factors described above, seeing the number of pods per tree, as described shortly, influenced farmers' beliefs about clonal cacao and hybrids, which helped explain their adoption.

Beliefs of Using Cacao Clones on Facilitating Labor

The adoption or rejection of clonal cacao was also correlated with participants' beliefs that this innovation influenced the way farming practices were done. The rationale for such connection was explained by the differences between the architecture of a hybrid tree and a grafted tree. Regarding the latter, the lower canopy height of some clones was reported for offering advantages for managing the plantation,

> Because hybrid cacao plants grow too high in some situations, one sometimes has to climb the tree to harvest the pods or climb the tree to prune it, so one wastes more time. In contrast, in the grafted cacao, one only needs a bag and a pruner [scissors], so one ends up harvesting the plantation more efficiently (Participant 19).

Even though many participants shared the belief that farm activities were easier to implement in clonal plantations, some participants affirmed the contrary. The previous was the case of participant 18,

> The truth is that I'm not totally supportive of grafting. I've always preferred hybrid because there are more resistant to diseases and are easier to manage. For instance, if you have a grafted tree and don't control weeds constantly, that crop will get damaged

as it is a susceptible crop. But if you left a hybrid tree abandoned for two years, then you can return and see that the plant is still producing.

Beliefs of Using Cacao Clones on Cocoa Beans Quality

Participants' convictions regarding the quality of either cacao clones or hybrids also supported the adoption decisions made by farmers. For the specific case of cacao clones, even though some participants recognized that cacao cultivars from San Vicente had been widely recognized for their quality, others acknowledged that extensively utilized cacao clones scored low on quality indicators. By way of illustration, participant 02 commented that "the Ecuadorian clone CCN51 is an excellent clone; however, [chocolate] companies don't like it because of its bitter flavor."

In contrast to clones, some participants were confident that the quality of the beans obtained from hybrid trees was better. This previous belief explains why some farmers did not decide to replace their hybrid trees with clonal cultivars. Participant 17, for example, indicated that "the beans from hybrid trees have a better quality; from those beans is that we obtain our chocolate," a belief that supported their current rejection of clonal cacao.

However, the adoption of clonal cacao did not necessarily mean that farmers' judgments about hybrids were negative. On certain occasions, farmers adopting clonal cultivars also recognized the advantages of using hybrids. Some farmers had even clonally propagated outstanding hybrids from their farms, as participant 19 affirmed when asked about their thoughts about the quality of clones and hybrids,

> I think that there is nothing better than the criollo [hybrids]. In any case, if one gets scions for grafting from an excellent criollo [tree], then one is propagating the same criollo that one has on the farm. On this farm, we have done it.

In some cases, however, farmers did not consider it relevant to adopt practices to enhance their cacao quality. Flaws in the value chain were among farmers' reasons for not being worried about cocoa quality; as participant 03 affirmed,

> We have a serious issue here, and it is that since we do not organize ourselves and seek higher-prices markets, it would be very complicated to focus on quality. At this moment, I could be following all the harvesting, fermenting, and drying recommendations to produce high-quality cocoa beans. However, when I take it [cocoa] to the local buyers in town, they will buy it at the same price as the junk that my neighbor could be producing. Then, it is not worth it to do all those practices.

According to participants, improving cocoa quality was not as important as increasing yields. Nonetheless, as was just described, their responses suggest that producing high-quality cocoa beans was still relevant to influencing clonal cacao adoption decisions.

Access to Resources

Beliefs of Using Cacao Clones on Farming Objectives and Access to Resources

Farmers' access to resources was helpful to understand the adoption of cacao clones. However, its influence on adopting clonal cultivars occurred when it moderated the relationship between farmers' beliefs about clones and their posterior adoption decisions. Participants indicated that even if they believe that cacao clones were essential to increase revenues, they did not adopt this innovation due to a lack of access to resources. Regarding the specific resources impacting their adoption decisions, participants did not mention that access to materials needed for grafting was a critical issue as it could be obtained from their farms (scions) or Fedecacao (seeds and scions). In contrast, farmers highlighted the resources needed to pay the grafter and to compensate for the loss in production resulting from changing hybrids for clonal cacao were the ones influencing their decisions. Participant 19 explained,

> Due to the economic situation, I wouldn't change them all [the hybrids] because I would have to do it little by little. The idea is that when some plants are becoming productive, I can eliminate some other ones. One cannot just decide to eliminate half a hectare or one hectare; the labors must be done little by little.

Beliefs About Using Cacao Clones on Objectives and AEAS

Access to the services provided by Fedecacao was critical to influence farmers' beliefs about using clonal cacao. Throughout a diverse set of activities provided by this AEAS provider, farmers became aware that using clonal cacao was vital to achieving their farming objectives. To influence this mental condition in which farmers had confidence about cacao clones, Fedecacao did not only *told* farmers the benefits of this innovation. Fedecacao also *showed* them so. In this way, farmers who had access to AEAS in San Vicente heard that adopting clonal cacao was fundamental to increasing revenues, a critical objective pursued by farmers. As a way of illustration, participant 19 said that "when the extensionists come [to their farm], I feel excited about grafting, about higher yields, about facilitating labor, harvesting, and pruning; thus, one starts replacing the hybrids for clones." Similarly, participants reported that AEAS providers influence their beliefs about clones when extensionists visually showed them the clones attributes, mainly through field trips organized by Fedecacao.

Seeing the Innovations' Attributes

Seeing was a way to learn about the characteristics of innovations, and this was particularly true for those innovations that pose highly observable attributes. Participants affirmed that relevant features of clonal cacao could be seen. This was the case previously described by participant 17 when said that "one can see" trees with a higher number of pods on their farm. This was also the case of participant 20, who said that "whenever we decide to adopt a particular clonal cultivar, we try to see it first in our neighbors' [farms]. We try to look which [cultivars] are the ones who get the fewer diseases, those that have higher productions." In this way, contrary to other innovations such as soil amendments, the observability of the cacao clones played a crucial role in shaping farmers' beliefs of using them.

Beliefs of Using Cacao Clones on Farming Objectives and Seeing the Innovations' Attributes

Seeing the number of pods hanging on a cacao tree influenced farmers' beliefs towards that tree cultivar. The previous affirmation, according to participants' responses, held for both clonal cacao and hybrids, as participant 13 recognized,

> I always say that everything enters through the eyes [first impressions last], and that's it. The experience of visiting a farm and seeing a highly productive crop, like the

one form <name of farmer>, that produces 4,000 kilograms per hectare, is an experience that changes anyone's mind.

The visual attributes of the cacao clones were also helpful to form the belief that this innovation facilitated the agricultural practices in a cacao plantation. In this regard, participant 13 said that "when one visits other farms, one realizes that, if there are grafted plants, it looks a nicer place to work."

While participants affirmed that seeing the characteristics of clonal cultivars and hybrids shaped their beliefs and their consequent decisions, they also recognized that exploring an innovation by themselves was critical. In other words, the perceived performance of an innovation resulting from its previous adoption influenced farmers' beliefs of using it.

Perceived Performance of Innovations

The adoption of innovation was far from being a simple linear process. Farmers' decision to adopt or reject an agricultural innovation was not the final stage in the adoption process. Indeed, as participants exemplified, the adoption of cacao clones was by itself a source of knowledge, a knowledge that farmers incorporated into their decision-making process. In this way, the perceived performance of clonal cultivars used here (

Figure *1*) reflects farmers' awareness about the performance of this innovation resulting from its previous adoption.

Beliefs of Using Cacao Clones on Farming Objectives and Perceived Performance of Innovations

In the early 2000s, the recommendations of clonal cultivars as planting material spread in Colombia. At that time, the adoption of cacao clones was not necessarily supported by farmers' beliefs about the clones. In other words, cacao farmers decided to adopt clonal cultivars even if they hadn't had any experience with the clones, nor they had seen them on other farms. Donations, instead, played a crucial role in the adoption of clonal cultivar; as participant 05 commented,

> [In San Vicente,] when the first nursery with clonal cultivar was established to produce grafted seedlings, Fedecacao had to give the plants free. Around 100-200 plants were given to innovator farmers with the idea that these farmers would experiment and see the differences between clones and hybrids.

Nowadays, however, the situation is different as most of the farmers in San Vicente have worked with cacao clones. When asked about the adoption of clonal cacao in San Vicente, participant 13 commented that "If we talk about the 3,600-3,700 families that grow cacao in the municipality, I estimate that among 3,000 of them there is one clonal plant. That there are two, five, ten, or 1,000 is a different thing." In this way, farmers' beliefs about clones were increasingly influenced by their own experiences. For example, participant 02 described how the previous experience with clones influenced their beliefs and adoption behavior,

> After considering the soil, temperature, and the optimal altitude for the cacao, you determine the variety [of cacao] based on your own experience. For instance, I've convinced myself about the best variety that I will keep utilizing over the years. Because I am still establishing new areas, I'm inclined to use the FSV41. Because my goal is to export cocoa to some craft chocolate companies in the United States.

Farmers' beliefs of using cacao clones towards achieving their farming objectives were relevant to understanding the adoption of this innovation. As previously described, the role of donations and access to resources were also important. However, even when these factors were considered, the explanation of why farmers adopt clonal cacao remained incomplete if the personality traits of farmers were not considered.

Personality Traits

Thoughtful Creativity

Thoughtful creativity helped to explain the adoption of clonal cultivars among cacao farmers. Those farmers who decided to adopt clonal cacao had to cope with a certain degree of uncertainty about this innovation, especially when farmers adopted recently released cultivars. Participant 20, who began to cultivate cacao six years before being interviewed, affirmed that their degree of thoughtful creativity could explain why they adopted clones while their neighbors did not do it. For participant 20, the adoption gap is explained because their neighbors "do not take risks…because they have the knowledge, but when there is a need to make a decision, they become frightened."

Another comparison regarding how thoughtful creativity influenced the adoption of agricultural innovations was made by participant 09. Even though the comparison context referred to coffee farmers in Santander, the quotation from participant 09 supported the generalization that the degree of thoughtful creativity influenced the adoption of innovations among farmers, particularly those from San Vicente,

> Look, the coffee grower from Santander is very attached to things. This is a different situation in Antioquia [another region in Colombia]. By way of illustration, farmers from Santander don't renovate their coffee plantation homogenously [as recommended] because when there is a plant that still has some [coffee] beans, they don't cut it. Therefore, within the plantations, there is a significant variation in coffee trees sizes in Santander, including San Vicente.

Having the right degree of thoughtful creativity, however, was desirable for some farmers. This was particularly true for adopting clonal cultivars, an innovation that could have severe repercussions for farmers when unsuccessful. The case of grafted seedlings described by participants and documented above is a good example of the relevance of being prudent regarding new ideas. However, as acknowledged by some participants, thoughtful creativity was also needed if farmers were to adopt new cacao varieties.

Conscientiousness Planning

Conscientiousness planning played a role in adopting clonal cultivars of cacao. According to participants, those farmers who saw their crop as a business were eager to increase farm productivity through technology adoption. As clonal cacao has been proven to be an essential innovation to improve cocoa production, farmers with considerable conscientiousness planning tended to rely on this innovation. Participant 13 said of the role of this personality trait,

> Some [cacao] producers see the crop as a business, something they are constantly being told, that one must see the crop as a business. Then, those producers who have renovated almost all their plantations are because they see in their cacao their business; they see in the cacao a way to increase revenues and, consequently, their family wellbeing.

How does the cadmium issue influence the adoption of innovations?

Cadmium (Cd) is an issue that could severely impact the future of the cacao sector in San Vicente. However, despite its relevance, none of the cacao farmers interviewed had modified their agricultural practices due to this heavy metal. Even though the cadmium issue has not been influential yet in promoting the adoption of cacao cultivars with low cadmium accumulation traits, this research identified two critical factors necessary to understanding this situation. The first one was farmers' knowledge of cacao cultivars as an alternative to Cd. The other one was farmers' perceived need to control Cd.

Farmers' Perceived Needs to Control Cadmium

In San Vicente, according to the responses provided by the participants, the level of awareness of the Cd issue varied across cacao farmers. In some cases, participants were not familiar at all with Cd. They have not heard the word "cadmium," nor were aware of heavy metal's existence with the potential to impact their livelihoods. There were other situations, however, where participants recognized that the Cd levels in San Vicente could threaten the commercialization of the beans, particularly in international markets,

> I've heard that countries like the United States and European countries don't want cadmium in cacao. I don't know the ppm [parts per million] limits; to be honest, I don't have that information. However, I know that there is an issue here in San Vicente because there are sectors, not all of them, that have a high cadmium content (participant 02).

Farmers who heard about Cd did so through diverse communication channels. Rather than mass media channels, interpersonal channels were the primary mechanisms to transmit messages about Cd across farmers in San Vicente. Being a member of a producers' organization seemed to be a relevant factor to hearing about Cd as this topic was discussed in meetings and through cellphone messages. Other farmers learned about Cd by looking at diverse information available on the internet. In most cases, though, word of mouth was the primary communication channel through which participants learned about Cd's existence and its potential consequences. Official institutional messages about Cd, on the other hand, were not frequent at all,

> The thing is that cadmium has been treated, I don't know, confidentially … As I told you, I belong to a [farmers'] cooperative. I have been part of the board of directors,

so together with <name of the organization>, we have done that type of research. But as I told you, they have not given us the results. They haven't told us about our cadmium levels (participant 06).

The uncertainty about the Cd issue among farmers from San Vicente was reflected in the lack of a mutual understanding. Participants' responses regarding the origin of Cd, its regulations, its consequences, and its mitigation were diverse. While participants agreed that the commercialization of cocoa beans might be affected by Cd regulations on chocolate, there was controversy regarding the objectives of such regulations. In some cases, as exemplified by participant 03 and participant 01, the regulations were not necessarily seen as a means to prevent health consequences of Cd intake,

> Once, we talked to a French person who was a representative of a European trading company. He said that he was doubtful about that famous cadmium. That perhaps the multinational companies themselves were falsely advertising it to disenchant the cacao farmers so they would sell their farms or abandon the cacao so they [companies] would take possession [of the land] and exploit the subsoil [mining resources] (participant 3).

A similar rationale for explaining the regulations on Cd in chocolate was presented by participant 01, who affirmed that,

> I see that Colombia has an excellent [cacao] genetic; the Colombian cacao, the cacao from Santander, has an exceptional unparalleled flavor and aroma. Then, if the farmers demand better prices for such reasons, there has to be a way to penalize it, and

that's it. So this is a marketing strategy to manipulate the advantages of the cacao. In the end, no one has said that the cacao will be rejected but that it would be cheaper to mix it with other products with low [Cd] contents, something illogical. The only thing I see is a business they have. People will not die from eating chocolate with ten parts per million [of Cd]; if so, we, the people from Santander, would be dead decades ago.

Despite the ambiguity of the Cd issue, participants affirmed that they had not yet been affected by this issue. As a way of illustration, when the initial four participants were asked about the critical threats of the cacao sector in San Vicente, they identified hazards that had to do with the cacao value chain, with commercialization flaws impacting the prices of the beans. They also identified environmental and biotic conditions as challenges to the sector. In contrast, none of the farmers initially recognized cadmium as a challenge to the cacao sector, even though some of them have heard about the issue. When participant 11 was asked about whether farmers feel a necessity to control Cd in cacao, the answer was,

I think people repeat what others say to them, but it is not that the farmers see it [Cd issue] as a necessity. Someone made the [Cd] issue fashionable, but it does not mean that someone sees it as a need.

Participants' responses indicated that farmers in San Vicente did not perceive an immediate need to tackle Cd. While some cacao farmers knew that Cd was an issue that could impact their livelihoods, unofficial messages spread misinformation about the nature of this problem. Still, some farmers did not hear about this heavy metal, and most of those aware of its existence did not know the Cd levels in their farms or the threshold levels. Under these circumstances, farmers from San Vicente did not adopt any agricultural practice aimed at tackling the Cd issue.

Knowledge Regarding Cacao Cultivars as an Alternative to Deal with Cd

Besides not perceiving the need to control Cd, farmers did not adopt agricultural practices to tackle this problem because they did not know what specific procedures could lower Cd levels in their farms. This lack of knowledge indicated that farmers had not been told the Cd mitigation strategies, primarily through institutional communication channels. This situation is exemplified in the following comment from participant 14,

> So far, there are no solutions [to the Cd issue]. We have been told about Cd, its consequences, and several other things, but not about its solution. We haven't heard, for instance, that "boron is helpful," no. No one has told us anything. The only thing that one hears is about the consequences of Cd in the body.

The lack of a clear message about Cd created speculations among farmers and extensionists in San Vicente. Rumors about the origin of Cd and its potential solutions spread through word of mouth, generating inconsistent information on how to tackle this heavy metal. Participant 06, for instance, commented that "it is believed, and one has heard, that the farms that do not use chemicals do not have Cd issues, that those [farms] that adopt chemicals have higher levels of Cd." Other farmers heard about using microorganisms and plants as possible solutions to this problem, as in the case of participant 19, who was told to establish sunflower to control the Cd issue. From the cacao extensionists' point of view, the solution lied in avoiding nutritional deficiencies. As a way of illustration, participant 13 affirmed that "farmers already know that if the plant has what to eat, it is not going to eat Cd because Cd is located deeper [into the soil]." In this manner, cacao farmers from San Vicente were being exposed to a series of inconsistent messages about the solutions to the Cd issue in cacao.

Even though some participants heard about diverse alternatives to deal with Cd, none of the messages suggested the use of cacao cultivars. Participants were aware that plant nutrition and bioremediation could be helpful practices to reduce Cd absorption by the cacao tree. However, there was a lack of understanding that the type of clonal cultivar influences cd absorption. Consequently, even if farmers wanted to address the Cd issue, they did not rely on cacao cultivars as an alternative as they were unaware of this potential solution.

The Soil Amendments Adoption Model

Specific Context

The adoption of soil amendments among cacao farmers from San Vicente occurred in a specific context that uniquely influenced the diffusion of this innovation. These structural conditions that created the particular context where this adoption process happened were varied. They were also unique to the innovation, the social system, and the location where the adoption process occurred. Providing sufficient information about these conditions, then, is important to enhance the model's credibility. Consequently, the context where the adoption of soil amendments among cacao farmers from San Vicente took place is described next.

Terminology

In agricultural settings, the term "soil amendment" is somewhat confusing as it covers various materials. Davis & Whiting (2013), for instance, classify soil amendments into two broad categories: organic, which include sphagnum, peat, wood chips, compost, manure, among others, and inorganic, in which vermiculite, perlite, tire chunks, and sand are included. In contrast, Li et al. (2019), use the term lime interchangeably with soil amendment. The Soil Science Society of America (2022) provides a comprehensive definition of soil amendment that clarifies the main objective of their use: "Any material such as lime, gypsum, sawdust, compost, animal manures, crop residue or synthetic soil conditioners that is worked into the soil or applied on the surface to enhance plant growth (continue)." This previous definition is also helpful as it clarifies that soil amendments are different from fertilizers: "Amendments may contain important fertilizer elements, but the term commonly refers to added materials other than those used primarily as fertilizers" (Soil Science Society of America, 2022).

In Colombia, the term soil amendment is relatively new. Its introduction, primarily by the plant nutrition industry, aimed to establish the difference between a lime (calcium and magnesium carbonates[23]) and other materials with the potential to improve the soil conditions, particularly sulfates (i.e., gypsum), silicates, as well as other products as Thomas Slag and phosphate rocks. The 2019 Colombian Technical Standard NTC-1927 (NTC by its Spanish acronym) classifies soil amendments into two groups (Díaz-Poveda & Sadeghian, 2020). The

[23] Calcium (Ca) carbonate is the main component of agricultural lime. In addition to containing calcium carbonate, Dolomite lime also contains magnesium (Mg) carbonate. When Ca carbonate and Mg carbonate are calcined, Ca oxide and Mg oxide are produced. Ca oxide is the main component of burnt lime. Ca and Mg oxides are the main components of burnt dolomite lime. When Ca and Mg oxides are hydrated, then Ca hydroxide and Mg hydroxide, the main components of hydrated lime and hydrated dolomitic lime, are produced.

first one refers to inorganic liming materials containing calcium and magnesium elements, usually in the form of carbonates, oxides, and hydroxides, and that do not have primary nutrients (NPK[24]). The second group refers to other inorganic soil conditioners containing secondary nutrients like magnesium silicates, calcium sulfate, etc.

In San Vicente, however, a soil amendment was usually referred to as a lime, which created misinformation about soil amendments' benefits. In this regard, participant 08, a soil amendment expert, explained,

> [In Colombia] the most used term is lime ("cal," in Spanish); it is so common that the verb "liming" ("encalar" in Spanish) was coined…I'm no friend of the use of lime nor of that term. I believe that the most adequate word is [soil] corrector or conditioner…When one uses [soil] correctors, one not only improves the [soil] chemistry but also its physical properties…then one ends up doing a more integral job when compared to what a lime does… Now, a right term is amendment. An amendment is to improve something that is not right…liming is to apply lime, but to amend or to correct [the soil] would be more accurate terms.

The development of the soil amendments market, which has come along with the release of new products, has made it more challenging to define what a soil amendment is. In Colombia, the soil amendment market took off in the 1980s, 20 years later than the chemical fertilizers market (participant 08). In the early times, Ca and Mg carbonates, in the form of agricultural and dolomite limes, were the primary products sold by soil amendments companies. Nowadays,

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[24] NPK accounts for nitrogen (N), phosphorus (P), and potassium (K).

however, companies in Colombia offer a portfolio of more than 30 soil amendment products (Rio Claro, 2022). Thus, besides the widespread agricultural and dolomite lime, the market of soil amendments covers a great diversity of products tailored to the equally diverse needs of farmers. The story told by participant 09, the manager of the most significant soil amendment company in Colombia, illustrates how the development of new products redefines the concept of what a soil amendment is,

> Our company has 40 years old… In the 1990s, we moved from [Ca and Mg] carbonates to <name of a product No. 1>; that product was very successful in the 90s. In the late 90s, we added gypsum [Ca sulfate] to this product, resulting in the famous <name of the product No. 2>; that was the next step. < Name of the product No. 2> is currently the most commercialized product in Colombia…With <name of a product No. 1> you have three nutrients, Ca, Mg, and silicon (Si); when you move to <name of a product No. 2>, now you have Sulfur (S), Ca, Mg, and Si.

For some participants, the difference between a lime and a soil amendment was unclear. In this way, the adoption of soil amendments among cacao farmers from San Vicente took place in a context where the definition of a soil amendment was blurry. For this reason, the words soil amendments and lime are used indistinctively in this research, even though their differences are recognized.

Availability of Soil Amendments

Farmers from San Vicente could choose to buy soil amendments in one of the several stores located in the town. However, once in the store, their freedom of choice was constrained due to the small number of soil amendment materials they could buy. Participant 12, for instance, affirmed that "regarding lime, we only sell <name of the product No. 1>; that is the only one we are offering…it is the one the most demanded by the people." The situation of participant 10, the other soil amendment provider interviewed, was similar, as, at their store, they offered three types of soil amendments. While both the number of soil amendment providers and the availability of different soil amendments in San Vicente increased in recent years, participants recognized that farmers' buying options were still limited. Participant 05, for instance, stated,

> One started to see soil amendments [in San Vicente] in the last five years. However, ten years ago, it was impossible to find many amendments. Sometimes one found agricultural lime; if one wanted dolomitic lime, however, one had to ask for it in advance as it was not a product offered in the stores.

The low diversity of soil amendments in San Vicente was not just the sellers' responsibility. Offering more than a few soil amendment products also created logistical challenges to the sellers, especially when the products had low rotation. In this regard, participant 08 affirmed that "for distributors, it is very complicated to buy soil amendments in a region where the [products'] rotation is very low…it is complicated as they have to storage [the product] until someone buys it." While identifying the reasons for the low availability of soil amendments in San Vicente is beyond the scope of this study, it is essential to point out that farmers' decisions to adopt soil amendments occurred in a context of a limited market.

Purposes of Using Soil Amendment

The limited offer of soil amendments in San Vicente and its often-confusing terminology also affected the way farmers perceived the benefits of using soil amendments. As one of the main objectives of liming (specifically for Ca and Mg carbonates and their derivates) is to reduce the soil acidity (Li et al., 2019), there was a general belief that all soil amendments were only valuable for increasing soil pH[25] (equivalent to reduce soil acidity). By way of illustration, participant 12, a soil amendment provider in San Vicente, commented that farmers "use [soil] amendments to control soil acidity," a belief held by other participants. However, besides lime, soil amendments also refer to several other products, which means that the benefits of using soil amendments go beyond only reducing soil acidity. Nonetheless, as participant 08 described, farmers still perceived soil amendments primarily as a product to increase soil pH,

> The most challenging part is to make farmers understand that an [soil] amendment is not only intended to increase [soil] pH. The truth is that an amendment is a product that also adds nutrients in addition to increasing or decreasing pH. And I say to increase or decrease pH because, in Colombia, we are used to the fact that the pH must be increased; however, if one goes to Mexico or the northern part of Colombia, the soils are alkaline [opposite acidic]. For instance, we currently sell soil amendment to decrease soil pH; we sell calcium and magnesium sulfates…then, soil conditioning is not only about increasing pH (participant 08).

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[25] pH is the chemical property used to measure the acidity or alkalinity in the soil. The pH value ranges from 0 (acid) to 14 (alkali). In agriculture, however, the values in the soil are usually between 4 to 10 (Sadeghian, 2016)

Farmers' confusion about the objectives of using soil amendments was connected to misconceptions regarding the different materials that could be used to amend soils. Thus, farmers did not usually know the main components of the soil amendments and how these were helpful or not to tackle their own needs. The challenge of making farmers aware of the different properties of soil amendment was also mentioned by participant 16,

> We have been talking about [soil] amendments for more than 15 years. In the beginning, it was very challenging. Farmers didn't differentiate between an amendment and a lime; everything was lime for them. We went through a process to make them aware that carbonate is not the same as sulfate or silicate, that they have different characteristics.

A relevant characteristic of soil amendments that farmers seemed to undervalue was their nutrient delivery into the soil. Farmers had been told that by increasing the soil pH, the bioavailability of toxic elements such as aluminum decreases. They were also aware, as participant 14 described, that when the pH is low, some nutrients needed by the plant react with the aluminum, reducing their availability,

> A friend of mine told me that when the soil is acidic, it is because there is a lot of aluminum, and aluminum encapsulates the food. It encapsulates it, and the plant cannot absorb it. Then, when [soil] amendments are applied, for instance, a dolomite lime, the nutrients will be liberated so the plant can absorb them. That is why one should apply lime.

However, as participant 08 recognized, the interviewed farmers did not recognize that the soil amendments are a source of essential elements needed by the plants.

> The thing is that, traditionally, the fertilizers have been considered the NPK [products], which is very common in rural areas. In contrast, when one talks about Ca, Mg, or S, which are secondary [elements], those are not considered fertilizers; but they are nutrients like NPK are.

Besides not considering soil amendments as a source of nutrients, the interviewed farmers were unaware of other benefits of using this innovation. Among those were the positive influence of soil amendment applications on the growth of nitrogen-fixing bacteria and the microbial populations responsible for the mineralization of organic matter (Díaz-Poveda & Sadeghian, 2020; N. W. Osorio, 2014). Farmers were also unaware that soil amendments are beneficial to reduce the availability of toxic heavy metals other than aluminum, such as iron, manganese, and cadmium.

Nutrient Requirements of Cacao

The nutrient requirements of the cacao tree are unique to this type of plant, a condition that has consequences on the adoption of soil amendments in this crop. Even though the exact nutrient requirements of cacao are not as well-known as for other species, and although fertilization recommendations have a weak scientific base (van Vliet & Giller, 2017), the mineral nutrition recommendations of cacao differs from that of other crops. Of particular importance are the differences between coffee and cacao. As an illustration, participant 08 commented that the lower limits of soil acidity for cacao and coffee vary. This participant affirmed that “the coffee

[tree] usually adapts well to a pH level of 5.0-5.5, while for cacao, it is ideal that the pH is higher than 5.5-6.0.” Under these circumstances, if cacao is established along with coffee in a farm with a soil pH of 5.0-5.5, soil amendments must be used for the cacao but not for the coffee plantation. A similar situation would be expected for any of the critical soil nutrient concentrations for cacao production (**Table *6***). In this way, the specific nutrient requirements of the cacao tree are essential conditions to understanding the adoption of soil amendments in cacao.

Table 6: Lower limits of adequacy of soil characteristics for cacao cultivation

		Available P (mg/kg)				
pH	% Total N	Sandy Soil	Clayey Soil	Ca	Mg	K
5.5	0.15	12	24	8	2	0.2

Note. The information of the table was obtained in van Vliet & Giller (2017).

Soil Conditions in San Vicente

The gap between the nutrients required by the cacao plant and the available nutrient in the soil determines fertilization recommendations for this crop. Thus, fertilizers are applied to cacao when the soil doesn’t offer the nutrients required by the plants. Consequently, knowing the characteristics of San Vicente’s soils is fundamental to understanding the adoption of soil amendments among farmers. And among the several aspects of the soils, two stand out: the soil pH and the cadmium (Cd) concentration.

A considerable percentage of the soils in Santander have low pH and high cadmium concentrations. Sadeghian (2016), for instance, reported that among 2,412 soil analyses conducted in Santander, 88% of them had pH levels lower than 5.0. Likewise, 74% of these analyses reported elevated aluminum levels, a toxic element that is available to plants when the soil pH is lower than 5.5 (N. W. Osorio, 2014). Regarding Cd, the recently released Cd map in Colombia (Bravo, Leon-moreno, et al., 2021) suggested that the average Cd content of 821 soil samples from Santander (1.9 mg Cd per kg of soil) was above the threshold value for agricultural soils (1.0 mg Cd per kg of soil).

Despite the high average levels, soil analyses also indicated that soils' chemical characteristics in Santander widely varied. Regarding Cd, for instance, Bravo, Leon-moreno, et al. (2021) showed that Santander was the Colombian state with the most extensive range between the minimum and maximum concentrations of Cd in soil. In some locations of Santander, Cd concentrations in soil were barely detected; in others, however, the Cd levels in soil were among the highest in the country. Interestingly, the variation of pH levels in San Vicente's soils was also found to be significant (Bravo & Benavides-Erazo, 2020).

Under these circumstances, farmers' decisions to adopt soil amendments occurred in a context where the highly diverse San Vicentes' soils had, on average, a low pH, and a high Cd concentration. These soil conditions in San Vicente indicate that the adoption of soil amendments became a recommended practice to fill the gap between the conditions needed by the cacao tree and those conditions offered by the soils.

History of Soil amendment Recommendations in Coffee

The history of cacao in San Vicente cannot be separated from the history of coffee, the most important crop in the recent history of Colombia. Besides being necessary to understand how this municipality became the cacao capital of the country, the connection between coffee and cacao is also helpful to understand the specific context in which San Vicente's farmers take decisions to adopt innovations. In this way, the history of soil amendments recommendations in the coffee sector is relevant to understanding how farmers in San Vicente have heard about the importance of liming.

In the 1980s, an important technological change in coffee cultivation happened: the National Federation of Coffee Growers of Colombia (Fedecafe) began to promote the use of lime. While the coffee plant tolerates acidic soil conditions, liming was identified as a critical practice to enhance the productivity of this crop, a situation that promoted its usage. Participant 08, who was part of this paradigm change, described,

> The usage of amendments started in the 80s. At that time, when I began to work in the federation [Fedecafe], it was forbidden to talk about lime in coffee. One couldn't speak about lime because it was said that it was detrimental because in calcareous soils, the coffee had lower quality, so one could not talk about liming. At that time, in the early 1980s, we started to research lime application and see the [plant's] responses. That's when the paradigm began to change.

While the use of soil amendments is at the core of the recommended practices in coffee (Sadeghian, 2008, 2016), this message was not equally communicated to farmers in all the Colombian regions. In Antioquia, participant 07 affirmed that "The federation [Fedecafe] has always recommended the use of soil amendments." This comment was later reinforced by the same participant who declared that "in coffee, [soil amendments] are widely adopted; agricultural stores offer a lot of products" (participant 07). In San Vicente, however, the situation was different as the recommendation of using soil amendments in coffee was a recent one.

Participant 09 affirmed that while working in San Vicente in 2011, "we barely recommended the use of lime." In this way, coffee farmers from San Vicente, most of whom were or became cacao farmers, did not hear from coffee extensionists about soil amendments as a critical agricultural practice. Participant 05 explained the situation in San Vicente,

> Until recently, the coffee federation [Fedecafe] incorporated the adoption of amendments in acidic soils within their recommendations. Before, it wasn't that way. Before, the advice was to apply [NPK] fertilizers, and that was something that cacao farmers heard because many coffee regions disappeared and turned into cacao, so farmers kept the knowledge they gained with the coffee.

Price of Fertilizers and Soil Amendments

This research was conducted when the prices of chemical fertilizers skyrocketed. Due to soaring shipping costs and the increasing price of natural gas used to run the fertilizer plants, Colombian farmers saw fertilizer prices double in just a few months. Participant 08, for instance, indicated that three months before the interview, a 50 kg bag of a widely used chemical fertilizer in Colombia costed COP 80,000, while three months later (Oct 2021), the cost was COP 150,000. In mid-November, participant 20 affirmed that in San Vicente, the price for that exact product was COP 195,000. Around that time, however, participant 12 was selling a 50 kg bag of soil amendment at COP 19,500, ten times less than the chemical fertilizer.

In contrast to the imported chemical (NPK) fertilizers, the price of the locally produced soil amendments was more stable. In some parts of the country, this price gap drove farmers' decisions to replace the application of the expensive chemical fertilizer with less expensive soil amendments. Soil amendments are not technically a substitute for chemical fertilizers as the former adds secondary elements (Ca, Mg, S, Si) while the latter usually includes primary nutrients (N, P, K). However, participant 16 affirmed that "in coffee, at the end of this year [2021], farmers are switching the [chemical] fertilizer cycle for an [soil] amendment cycle." In San Vicente, however, none of the participants interviewed indicated that the higher prices of fertilizers influenced their adoption decision regarding soil amendments, even though they recognized the significant prices gap.

While being cheaper than chemical fertilizers, the prices of soil amendments in Colombia also varied depending on the product's type and characteristics. Several reasons explained the price variability of soil amendments. There were situations where the production of certain materials was more resource demanding. For instance, agricultural lime was among the cheapest soil amendments as its production only requires crushing limestone. In contrast, burnt lime was more expensive as its production implies the calcination of agricultural lime. The high transportation costs in Colombia also played a crucial role in the price of soil amendments. In this way, as participant 08 acknowledged, there were situations where "the transportation cost was higher than the product itself." The mesh size, an indicator of the particle-size distribution of the product, was another factor that influenced the price of soil amendments as the smaller the particle size, the higher the cost of the product.

The price differences of soil amendments influenced the type of product that farmers bought. This was particularly true in San Vicente, where farmers were usually unaware of the different characteristics of soil amendments. As participants described, farmers tended to buy the cheapest soil amendment without considering the potential benefits of getting a more expensive one. Participant 16, for instance, affirmed that "it is hard for farmers to understand that a bag of dolomite lime costs COP 9,000 to 10,000 and that the same amount of another amendment costs around COP 30,000." A similar comment was made by participant 10, who affirmed that farmers usually ask them, surprised, about the higher prices of certain soil amendments. Participant 10 commented, however, that once farmers try the more expensive soil amendments, they usually rebuy them due to the positive crop response to their application.

Quality of Soil Amendments

The quality of a soil amendment did influence its price and its effectiveness. In Colombia, the 2006 Colombian Technical Standard NTC-5424 defines the conditions that soil amendments must fulfill. Two of these conditions are the minimum content of active ingredients in the amendments and the particle-size distribution of the materials. Burnt lime, for instance, must contain at least 70% of Ca, expressed as calcium oxide (Cao), while agricultural lime must have no less than 39.2% (Díaz-Poveda & Sadeghian, 2020). Regarding the particle size, soil amendments must not have particles larger than 840 microns (mesh size 20), and at least 50% of the particles must be smaller than 149 microns (mesh size 100) (Díaz-Poveda & Sadeghian, 2020). Due to the low solubility of liming materials (i.e., the solubility of Ca carbonate is 0.013 grams per liter of water), the smaller the particle size of a soil amendment, the higher the surface area, consequently the higher its reactivity in the soil. In this way, even for the same type of soil amendment (i.e., agricultural lime), its efficiency will depend on its quality.

Even though the NTC-5424 sets the rules for the quality of soil amendments in Colombia, the reality is that relevant characteristics of soil amendments vary. Díaz-Poveda & Sadeghian (2020), for instance, evaluated the quality properties of 30 amendments widely used by coffee farmers in Colombia. For some products, the previous authors found that active ingredients' content was below those required by the NTC-5424. Regarding the mesh size, participant 08 commented,

> The quality of an amendment varies according to the mesh size. If the particle is large, the quality of the lime is low, and its effect is limited, or there is no effect at all; it is also very cheap. There is a lot of that, very low-quality limestone with low carbonate contents and low purity. Here in Colombia, there are places where they sell that type of limes, and they are very cheap, COP 8,000 to 10,000 a bag.

Adoption of Soil Amendments

Among those farmers who provided information about the adoption of soil amendments **Table 3**, half of them affirmed they did adopt this innovation within two years before the interview. Dolomitic lime was the most widely used soil amendment, which indicates that Ca and Mg, in the form of carbonates, were the primary elements supplied to the soil. Only one participant reported having used a soil amendment containing various elements other than Ca and Mg,

> Here we are no longer working with limes; we work with other [soil] correctives that, in addition to lime [Ca and Mg, primarily], supply other elements, so they are complete products. In some farms, lime is still used, but that is not our case anymore because now the [soil amendment] companies have reinvented, so they do not only sell the lime to you (participant 01).

The dosage of soil amendments used by farmers and the application form of this product were similar across respondents. Those farmers who adopted soil amendments on already-establish cacao plantations applied the product on the soil's surface rather than incorporating it under till systems. Regarding the dosage utilized, farmers applied between 350 g and 600 g of soil amendment per plant. The frequency of application, however, was disparate across participants. While none of the participants used soil amendments more than once a year, some participants did it yearly while others, such as participant 14, only did it occasionally,

> I have applied [soil amendments] like three times in a row. The recommendation is at least once a year; however, one does not have the resources to do so. I had not applied [soil amendment] for two years. This year I did apply it.

The remaining half of the respondents who provided information about the adoption of soil amendments indicated they had not used them within two years before the interview. Thus, those farmers who applied soil amendment but did so outside this timeframe were considered non-adopters of this innovation. The case of participant 19 exemplified this previous situation as the last time she used soil amendments occurred three years before the interview. Participant 18's situation, in contrast, illustrated the case of a non-adopter who did consider it unnecessary to use soil amendments, a belief that explained his permanent rejection of its adoption.

The concepts influencing the adoption of soil amendments in San Vicente are described in **Figure 2**. The factors found to directly influence the adoption of cacao clones were grouped into five categories: 1) Donations, 2) Access to AEAS, 3) beliefs of using soil amendments on farming objectives, 4) personality traits, and 5) perceived need to control soil acidity. A sixth factor, farmers' perceived need to control cadmium, was included in the SAAM. Despite its irrelevance to explain the adoption of soil amendments (reason for using dashed lines), this sixth factor was integrated into the model to approach the question that asks how cadmium influences the adoption of this innovation. **Figure 2** also shows how the extent to which farmers followed recommendations provided by AEAS providers moderates the relationship between access to AEAS and the adoption of soil amendments. The SAAM diagram also shows how farmers' knowledge of soil amendments' influence on soil pH moderated the relationship between the perceived need to control pH and the adoption of the innovation. Next, the impact of each concept on the adoption of soil amendments is presented. The order in which they are described does not imply a ranking in their importance.

Donations

Some of the participants who applied soil amendments on their cacao plantations did so because this innovation was given to them as a donation. Even though none of the farmers reported to have received soil amendment donations recently, they confirmed that, at some point, the adoption of this innovation was supported by those incentives.

Soil amendment donations were given to farmers primarily through projects. As **Figure *2*** illustrates, those projects mainly had benefited members of farmers' organizations. Participant 19, for instance, commented that three years before the interview, she received 20 bags of lime thanks to a project that was granted to her organization. A similar situation occurred to participant 14, who received 40 bags of lime through a project awarded to an organization he belonged. While donations did not explain the recent adoption of soil amendments among the interviewed farmers, participant 16 affirmed that the influence of projects on the adoption of soil amendments in Santander was still relevant. When asked about the role of projects in the adoption of soil amendments, participant 16 answered,

> They [projects] are very important, and I believe they have supported soil amendments' adoption. We have participated in several bids, and we have gotten many of them. In Santander, where more bids have come up … in most of these bids, they have selected the <name of the product> as the [soil] amendments for those projects. And the people apply them, of course. While I'm unsure if they [soil amendments] are given for free or at a discounted price, the reality is that many of those projects have relied on <name of the product>, which is something that has undoubtedly helped us.

Access to agricultural extension and advisory services (AEAS)

The information and recommendations provided by AEAS influenced the adoption or rejection of soil amendments. In some cases, farmers used soil amendments because they were told, by an extensionist, to do so. The previous was the case of participant 02, who commented: "When I began to sow, the agronomist engineer recommended to me, according to the soil analysis, to use 600 g per plant. Thus, I used 600 g of dolomitic lime." In this way, the recommendations provided by AEAS not only influenced farmers' adoption behavior but also determined the type and dosage of soil amendment used. Both participants 10 and 12, providers of soil amendments in San Vicente, affirmed that some farmers who bought this product at their stores were clear on the type and amount of product needed.

The recommendations of applying soil amendments usually responded to soil analyses indicating such necessity. However, the soil analyses are difficult to read, so the advice to use soil amendments based on soil analyses were usually generated by extensionists with the knowledge to do so. Besides Fedecacao, the leading AEAS provider in San Vicente, farmers' soil analyses were read by professionals from diverse institutions, including private companies. Participant 16, the manager of a soil amendment company, affirmed that they offer farmers the service of soil analysis interpretation, and participant 10 affirmed having an agronomist engineer who interpreted soil analyses at the store. For his part, participant 14 commented,

> We were on training with <name of the company>, and they did the analysis and recommendations. One of the recommendations was to use lime. So, I applied lime. I used approximately one pound, 500 grams per plant.

However, there were other cases where extensionists' recommendations discouraged the use of soil amendments, particularly the adoption of liming materials. Strictly speaking, lime is made up of Ca and or Mg carbonates or their derivates, all of which are alkaline materials generally recommended when there is a need to increase soil pH, control toxic elements, or supply secondary elements. Therefore, extensionists in San Vicente advised farmers not to apply lime when there was not needed because its usage could have caused negative consequences. The previous was the situation of participant 20,

> Yes, we applied [lime] to some plants, and they turned yellow. So, an [agronomist] engineer came and told me: "no, you cannot use [lime]; we are still going to

do the soil analysis." And it was right; we could not use it because it [soil] had too much lime, so they [plants] turned yellow.

Follow AEAS Recommendations

The recommendation of using soil amendment and its consequent adoption by farmers was not always straightforward. In some cases, participants reported that even though farmers heard from extensionists that their soil needed soil amendments, some farmers have not followed such recommendations. There were situations where farmers modified the guidance provided by extensionists. Participant 03 commented how he adjusted the dosage of soil amendment recommended to him,

> When one looks at the recommendations made with the soil analysis, one has to apply one kilogram [per plant] or one ton of lime per hectare. I am not doing it that way; instead, I'm using 500 g every year.

There were other cases where farmers did not follow the recommendation to adopt soil amendments. Participant 19, for instance, had not adopted soil amendments in more than three years, even though she affirmed that "we have always been recommended to use dolomitic lime for the [soil] acidity, especially in these soils that are very acidic." Participant 16 reaffirmed the previous comment when he commented that "it is infrequent that a farmer buys a [soil amendment] product after attending a talk [about soil amendments]."

Beliefs of Using Soil Amendments on Farming Objectives

Farmers' beliefs about how using soil amendments influenced productivity were relevant to explaining this innovation's adoption. Participants who adopted soil amendments reaffirmed their conviction that this practice was beneficial to increasing cocoa productivity. As a way of illustration, participant 14 commented that "once you apply lime, the aluminum will release the nutrients, so the plant will be able to absorb them, and it will then produce." In contrast, those participants who rejected using soil amendments at their farms did so because they believed that its usage did not have any impact on the cacao plants. Participant 15, who refused to use this innovation, said,

> I did not see positive results, so I realized, and I said: “no, no, no, I do not see that this [lime] works.” It turns out that I did it [apply lime] only twice, and then I realized, and I said to my son, “it seems that we are losing money, instead.” Besides not having enough money, we are losing it.

In this way, farmers’ confidence that using soil amendments was beneficial or detrimental to cocoa production was critical to understanding the adoption of this innovation. The beliefs held by farmers regarding using soil amendments were influenced by their own experiences using this innovation. Word of mouth was also a relevant source of information that influenced farmers' opinions about applying soil amendments to their cacao plantations.

Beliefs of Using Soil Amendments on Farming Objectives and Perceived Performance of Soil Amendments.

The previous adoption of soil amendments was a source of knowledge that allowed farmers to become aware of the consequences of using this innovation on their farms. This awareness gained from hands-on experience supported farmers' confidence regarding the outcomes resulting from using soil amendments. The previously described situation of participant 15 exemplified how the perceived performance of soil amendments, resulting from its previous adoption, shaped his beliefs about the benefits of using this innovation. The knowledge that participant 15 gained after seeing that the application of lime did not have any results on the plants translated into a belief that using lime was an unnecessary, costly effort, a view that supported its rejection.

On the other hand, participants believed that using soil amendments was relevant to increasing production because they saw positive results when previously applied on their farms. In some cases, however, the observed effects were not necessarily higher cocoa production but positive changes in the cacao plant condition that were connected to higher yields, such as greener leaves. In other situations, the observable results of using soil amendments had to do with the response of plant species used as indicators of soil acidity, a factor that, according to participants, limited the productivity of the cacao crop. Participant 14 said of perceiving the performance of soil amendments at his farm,

> Look, an indicator of [soil] acidity is the soil cover. For instance, there are areas here where there are many ferns … so I applied [soil amendments] the year before last,

> especially on the high lands. So, I uniformly distributed the material on the soil surface, and I noticed an 80% reduction in the fern. Therefore, it is good.

Beliefs of Using Soil Amendments on Farming Objectives and Hearing the Innovation's Attributes

Farmers also learned about the benefits of using soil amendment because someone told them so. Hearing about the attributes of this innovation was particularly relevant when participants had not experienced the consequences of its usage. In San Vicente, word of mouth was a critical communication channel used by farmers to share information about the adoption of soil amendments. Participant 12, a soil amendment provider, exemplified how word of mouth influenced farmers' decisions,

> Some farmers decide to apply lime because their buds did it. That's what one hears from them. Sometimes it is because their neighbors have had positive results working the land that way. The persons who do not use soil analysis seek advice from their bud, neighbor, or friend who has already done so and had a positive result. They say, "I will do it that way because we are neighbors and the land is somehow similar," which is very common here.

Personality Traits

The inherent farmers' characteristics were also helpful to understanding the adoption of soil amendment in San Vicente. Farmers' attitude to new ideas, defined previously as thoughtful creativity, was not reported as a helpful trait to explain the adoption of this innovation. In contrast, farmers' level of conscientiousness planning was identified as an influential factor in the adoption of soil amendments.

Conscientiousness Planning

Conscientiousness planning helped to explain the adoption of soil amendments among cacao farmers. Farmers who saw their crop as a business, an indicator of conscientiousness planning, were eager to increase farm productivity by adopting innovations. Those farmers who were constantly seeking to increase productivity saw the adoption of soil amendments as a way to improve the soil condition and thus a vital practice to improve their crops. Participant 16 said about the role of conscientiousness planning in the adoption of soil amendments,

> Cacao and coffee are different from industrial agriculture, in which farmers are always finding ways to improve and are non-conformists. Sometimes, a cacao or coffee farmer says, "I produce a certain amount and am ok with that." So, they enter into a comfort zone, not all of them. Still, it often happens…because when one sees the philosophy of the avocado or the banana farmer, it is an industrial philosophy of permanently increasing yields. Thus, if farmers always have in mind increasing productivity, they will always seek ways to improve, which is very important. Why have we grown with soil amendments? Honestly, we have found industrial crops where a value has been given to soil amendments.

In San Vicente, however, the value farmers gave to soil amendments mainly had to do with their importance in decreasing soil acidity. Therefore, farmers located on farms with adequate soil pH did not adopt soil amendments, even if the farmers had a high level of conscientiousness planning.

Perceived Need to Control Soil pH

In San Vicente, when farmers adopted soil amendments, they felt the necessity to increase the soil pH. Thus, farmers' rejection of this innovation was connected to their beliefs that the soil acidity at their farms was not an issue they should be worried about. As a way of illustration, participant 18's response to the question of whether soil amendments were used at their farm was: "no, the soils of the farm are not acidic soils, so there is no need to apply lime." In contrast, participant 15 answered: "I am using dolomitic lime as there is some [soil] acidity based on what you can see." In this way, farmers' recognition that soil acidity was an issue at their farms drove cacao farmers' decisions to apply soil amendments.

The knowledge that led to farmers' recognition of soil pH as an issue came from two primary sources: soil chemical analysis and visual recognition of indicator plants. In those cases where farmers had soil analysis, the specific soil acidity level was well known. Participant 14, for instance, knew that at his farm, "the soil is acidic as the pH is 4.5." This knowledge, in turn, supported his decision to use the soil amendment. Farmers also used plant species utilized as indicators of soil acidity to make soil amendment application decisions. Participants reported that two types of plants that indicated low soil pH levels were those belonging to the genera *Cyperus* (nutsedges or "cortadera" in Spanish) and *Pteridium* (ferns "helechos" in Spanish).

Knowing Soil Amendments on pH Control

The relationship between the farmers' perceived need to control soil pH and the consequent adoption of soil amendments was moderated by farmers' knowledge about this innovation. Without the knowledge that soil amendments were helpful to increase soil pH, farmers would not have decided to adopt this product. In San Vicente, however, there was a general understanding that the application of soil amendments sought to reduce soil acidity. Participant 13, for instance, affirmed that most farmers in this municipality were aware of the connection between soil acidity and liming,

> All of them [producers] are like that [they connect]: soil acidic, liming; soil acidic, liming… We know that there is a need to maintain a Ca/Mg relationship, among other things. However, for the producers, it is only liming to controlling acidity.

In this way, when a farmer perceived the need to increase soil pH, their decision to liming was supported by their knowledge that this practice was a potential solution to their needs.

Knowing soil amendments on Cd alleviation

Farmers' knowledge about soil amendments was limited to the domain of its influences on altering soil acidity per se. While some farmers were aware of how the soil pH influenced the availability of toxic elements, mainly aluminum, they did not know that the soil pH also influenced Cd availability. In this way, farmers did not know that soil amendments were an alternative to deal with the Cd issue. However, as discussed previously (see the "farmers' perceived needs to control cadmium" section above), this lack of awareness did not affect the adoption of soil amendments because farmers did not perceive the need to control Cd.

CHAPTER 5

DISCUSSION, CONCLUSIONS, LIMITATIONS, AND RECOMMENDATION

Introduction

Together with the literature, the data provided by the participants served as the foundation for the development of the Soil Amendments Adoption Model (SAAM) and the Cacao Clones Adoption Model (CCAM), which describe the adoption of these innovations among cacao farmers from San Vicente de Chucuri. Creating these models that identify the factors involved in the adoption of clonal cacao and soil amendments fills a gap in the literature and provides the foundations for the design and implementation of effective interventions using these technologies.

The SAAM and the CCAM add to the literature of behavioral frameworks illustrating the diffusions of agricultural innovations. Under those circumstances, this chapter aims to compare the frameworks created in this research and those models reported in the literature. This dissertation chapter also presents the research conclusions highlighting the contribution to the discipline of adoption research. The readers of this dissertation should also be aware of the issues weakening the quality of the study. Thus, the study limitations are also described. Finally, this chapter suggests a series of recommendations derived from the study. These lessons are intended to guide future research efforts to understand the adoption of agricultural innovations in perennial systems and offer insights that could be considered for future programming efforts.

Studying the adoption of innovations is challenging as human behavior is a complex phenomenon investigated by various scientific disciplines. Breaking down the facets of this complex, multifaceted phenomenon into categories (scientific disciplines) is a cognitive strategy for making sense of all these factors affecting human actions (Sapolsky, 2017). Under those circumstances, human behavior can be studied from a biological, psychological, economic, or even a sociological perspective, to mention some of the most relevant disciplines concerned with this phenomenon. Although scientists tend to rely on a particular field, it is crucial to recognize that all these areas of knowledge are entirely interconnected regarding explaining behavior. In the same way, it must be acknowledged that there is a diversity of positions upon which we can approach this complex phenomenon, making the comparison of adoption studies challenging.

Social theories help understand the social world, including complex situations such as the case of adoption behavior. Theories help us see chaotic environments logically by explaining how and why events occur. In this way, theories of human behavior can help understand the differences in the adoption of innovations. However, despite the benefits that theory brings to the research practice, the abundance of theoretical and conceptual frameworks in the adoption of agricultural innovations generates confusion. In particular, the diversity of adoption models has created a divergence in how this phenomenon is understood, resulting in confusing findings regarding the relevant factors that explain the adoption of innovations in agricultural settings (Montes de Oca Munguia et al., 2021).

The abundance of explanations about adoption behaviors also means that comparing the results of this research with other models explaining the adoption of innovations is a challenging endeavor. Besides the immense number of concepts researchers suggest relevant to understanding the diffusion of innovations, making overall comparisons of the SAAM and the CCAM to other models is difficult because of the numerous alternatives used by researchers to measure concepts. Thus, different clarifications of the meaning of a concept[26] (conceptualization) and various procedures used by researchers detailing the observational values representing the concept (operationalization) constrain the effort of developing a shared body of knowledge, which is the goal of this chapter.

Discussion

The CCAM (Figure 1) and the SAAM (Figure 2) are visual devices depicting the relationship between the concepts that influence the adoption of clonal cacao and soil amendment in San Vicente de Chucuri. On one page each, these figures answer the research question of this dissertation by offering two empirical models explaining the adoption of these two innovations. In this way, both visual models become the template for discussing the literature with the results of this study.

The context in which farmers' decisions took place, as Figure 1 and Figure 2 illustrate, was at the core of the CCAM and the SAAM models. The adoption of clonal cacao and soil amendments by cacao farmers from San Vicente was affected by contextual factors. Some of these factors, listed within the overall context, illuminate the broader system in which the diffusion of these innovations occurred. In the same way, the specific context of each innovation

[26] To facilitate the reader's identification of concepts in this chapter, all the concepts within this research will be presented within quotes (i.e., "relative advantage" and "beliefs about using the innovation").

was relevant to understanding the factors that influenced farmers' decisions specific to each technology.

The elucidation of the context in which adoption behaviors occurred was critical to the research endeavor for diverse reasons. First, the investigation of the context might illuminate researchers about possible pro-innovation bias, one of the most notorious shortcomings of diffusion research (Rogers, 2003). Thus, having a clear idea of the broader system in which innovations are adopted might be helpful in overcoming the researchers' bias that a new idea or product should be diffused and adopted by all members of a social system. Second, the contextualization of the phenomenon is fundamental because, without context, the readers of the research cannot fully understand why events occurred (Corbin & Strauss, 2008, p.306). In this way, as Creswell & Poth (2018) suggest, providing a detailed, thick description of the participants and the settings under study is a strategy to enhance the quality of the study as it enables the reader to transfer information to other settings.

Despite the importance of elucidating the factors that constrain or enable adoption decisions, adoption models usually leave out the context in which the phenomenon of study occurs. Contrary to popular adoption frameworks, the CCAM and the SAAM highlight the importance of the context, considering it a critical part of the model. As a way of illustration, none of the models explaining the adoption of agricultural innovations described by the review of Montes de Oca Munguia et al. (2021) considered it relevant to include the context as a component of such models. In contrast, the two conceptual frameworks developed in this research visually depict the context in which all interactions occur. Under these circumstances, the lack of context information in adoption models restricts making comparisons about the social, economic, and environmental conditions under which adoption occurs.

However, the absence of context in adoption models does not necessarily mean that adoption studies lack to include information about the structural conditions influencing adoption behaviors. To clarify the adoption phenomena, some authors make an extraordinary description of the context where adoption decisions materialize. The research of Ruf (2012), included in the systematic literature review in chapter 2, provides a good illustration of an adoption study describing the social and political context in which adoption occurred. In an effort to explain small farmers' adoption of rubber in Côte d'Ivoire, Ruf (2012) illustrates how immigration dynamics, together with a particular political context, facilitated the adoption of rubber in this West African country. More particularly, this previous author shows how demographic pressure led to the forest degradation of some regions in Côte d'Ivoire, which reduced the productivity of cacao crops that were growing in an environment without the benefits of the forest. This decline of the Ivorian cocoa sector, in turn, promoted the adoption of clonal rubber, a more robust crop that, in addition to being more labor-intensive during the establishment period, was able to grow without problems in degraded lands. By providing this information, Ruf (2012) contextualized how access to projects and rubber prices influenced the adoption of clonal rubber in Côte d'Ivoire. Under similar circumstances, looking at the history of the cacao sector in San Vicente was helpful in understanding how the coffee sector influenced the environment in which cacao farmers adopted innovations.

The importance of considering the context in adoption research was recently highlighted in a special issue published in the Applied Economic Perspectives and Policy journal (Pannell &

Zilberman, 2020). In one of the papers published, Llewellyn & Brown (2020) affirmed that in developing countries, agricultural innovation contexts are particularly complex and influence the diffusion of innovations in particular ways. In this way, a higher dependence on agricultural-based livelihoods, heterogeneity among farms and farmers, and access issues and scarcity of resources call for consideration of the context in which adoption occurs.

A relevant characteristic of the social context of developing countries is farmers' orientations towards objectives other than profit (Llewellyn & Brown, 2020). Adoption decisions made by small farm holders from developing regions do not necessarily respond to an intention of increasing revenues. This previous affirmation is supported by Schroth & Ruf (2014). They illustrate how farmers' objectives of stabilizing income, maintaining food security, and reducing risks influence their decisions regarding tree crop diversification in the humid tropics. Schroth & Ruf (2014) cite how coffee and cacao farmers' adoption of rubber and oil palm adoption has been motivated by farmers' desire to stabilize income. In this way, adopting crops that can be harvested all year round, contrary to crops that do not offer any harvest for several months of the year, is a strategy followed by farmers that do not necessarily follow a profit-increasing rationale. In this research, the participants' responses were consistent with the affirmation that farmers' objectives of adopting technologies are not necessarily economically driven. Remarkably, the interviewed cacao farmers suggest that in the case of San Vicente, maintaining food security and stabilizing incomes were relevant objectives that explain land-use decisions. In this way, strategies such as the establishment of banana, plantain, cassava, and avocado, among other food crops, responded to farmers' interest in enhancing their food security and having an income source during the establishment period of the cacao crop when the plants were not productive.

Nonetheless, as participants in this research described it, the adoption decisions happened in a context in which farmers' main objective was to increase revenues. Under those circumstances, the interviewed farmers behaved as profit maximizers following strategies aimed to either augment the amount of cocoa harvested on the farm or increase its sale price. Adoption studies have strongly supported this assumption that farmers adopt agricultural innovations to increase their revenues (Rogers, 2003; Schroth & Ruf, 2014; Weersink & Fulton, 2020). Likewise, improving agricultural productivity by growing farmers' adoption of new technologies remains a core strategy of agricultural transformation efforts, especially when it is assumed that higher yields resulting from technology adoption would spur economic growth among small farmers (World Bank, 2015).

Given the importance of farming objectives in adopting innovations, adoption models have emphasized the relevance of studying how adopters perceive the value of innovations towards accomplishing such goals as an explanatory variable. In other words, models suggest that adoption is dependent, among other factors, on the features of the technologies. The "relative advantage" of an innovation, defined as the degree to which a new idea is considered as being better than the one it supersedes (Rogers, 2003), is a well-known characteristic of technologies that several diffusion models have proposed. The ADOPT model, for instance, places the "relative advantage" and the "learning of relative advantage" as the primary economic and sociological constructs explaining the adoption of agricultural innovations (Kuehne et al., 2017). In the same way, influential models such as Rogers' (2003) Diffusion of Innovations theory suggest other characteristics of innovations relevant to understanding adoption behaviors like "compatibility," "complexity," "trialability," and "observability."

Despite the importance of considering the features of technologies, adoption studies have prioritized other types of categories in their analysis. In the systematic review of literature conducted in chapter two of this research, none of the categories utilized focused on the characteristics of the technology. In contrast, the variables included in the reviewed studies were grouped into (1) household characteristics, (2) wealth indicators, (3) access to information, (4) access to markets, (5) farm characteristics, and (6) extension characteristics. A similar result was obtained by Montes de Oca & Llewellyn (2020) after analyzing a sample of 100 adoption studies to characterize the explanatory variables used in those papers. According to the previous authors, the innovation characteristics accounted for 10% of the total variables included in the studies, being the least researched category. In this manner, variables related to the innovations like "profit advantage," "ease & convenience," or "relative advantage" were not popular among adoption studies, even though these variables had a high degree of consistency in explaining adoption behaviors (Montes de Oca & Llewellyn, 2020).

On the other hand, the authors above reported that these 100 studies stressed characteristics of the adopters (i.e., level of education and age) and characteristics of the context (total farmed area and income level). Interestingly, the systematic literature of chapter 2 also suggests that the category of households characteristics, which included the variables age, gender, and education level, among others, was emphasized by the studies analyzed. Thus, adoption studies tend to ignore the role of the variables related to the innovation itself.

The CCAM and the SAAM created in this research are made up of constructs belonging to a wide range of categories. As a way of illustration, within the CCAM, the construct "beliefs of using cacao clones on farming objectives," which reflects farmers' level of confidence that using this innovation is beneficial for them, could be located within the category characteristics of the innovation used by Montes de Oca & Llewellyn (2020). In the same manner, this last category could include the variables "seeing the innovations" attributes' and the "perceived performance." The CCAM and the SAAM also have variables that could fit within the categories of characteristics of the adopters (i.e., personality traits and knowledge) and the characteristics of the context (donations and extension). Likewise, both models describe the overall social, economic, and environmental context in which cacao clones and soil amendments were adopted. In the same way, the overall context is complemented by a narrative of the specific conditions influencing the diffusion of each innovation.

Still, it is essential to mention that the CCAM and the SAAM were developed using a particular research methodology with characteristics that differ from those used in popular adoption studies. Qualitative research, the methodology utilized to create both models, allows the researcher to include a wide range of constructs in addition to a detailed context. Unlike quantitative studies, in which researchers use a conceptual framework, set hypotheses, identify variables and determine their relationship, qualitative studies like the one conducted here are best at elucidating perceptions, attitudes, and processes (Glesne, 2011). In contrast, quantitative research seeks to make testable predictions and describe the causal process that connects events. In this way, the exploratory nature of qualitative research gives the researchers more flexibility on the types and numbers of variables used to explain a complex phenomenon. On the other hand, quantitative studies on the adoption of innovations usually rely on social theories that, by nature, should be the result of abstraction and should focus on the heart of the phenomenon (Van Lange et al., 2011). Under those circumstances, quantitative studies, depending on the discipline, might involve diverse and sometimes excluding factors of interest.

The adoption of innovations is a phenomenon that belongs to the convoluted realm of human behavior. Therefore, the adoption of agricultural innovations has been studied from the perspective of individual disciplines, namely economics, marketing, sociology, and psychology. An excellent illustration of how models differ based on the discipline is documented by Montes de Oca Munguia et al., (2021, p. 4), which is presented here in **Table 7**. Streletskaya et al. (2020) also illustrate how two kinds of literature - agricultural adoption and behavioral economics research- studying the same phenomenon, approach it from diverse perspectives. Streletskaya et al. (2020) show how behavioral economics seeks to unpack the black box of individual decision-making by studying intrinsic factors such as adopters' preferences and cognition. In contrast, agricultural adoption research goes for an understanding of extrinsic factors such as socio-economic and political ones on the adoption of innovations.

Table 7: Comparison of three classes of models of innovation adoption

Discipline	Class of Model	Description	Assumptions
Marketing	Contagion and inertia	People adopt when they come in contact with others who have already adopted; that is, innovation spreads much like epidemics.	Process initiated by mass communication and propelled by word-of-mouth, mediated by resistance to change (i.e., inertia).
Sociology	Social influence	People adopt when enough other people in the group have adopted.	Social exposure. Innovations are spread by a conformity motive mediated by resistance to change
Economics	Social learning	People adopt once they see enough empirical evidence to convince them that the innovation is worth adopting, where the evidence is generated by the outcomes among prior adopters and other relevant information sources.	Decision depends on prior beliefs, the amount of information gathered, and idiosyncratic costs.

Author: Montes de Oca Munguia et al., (2021, p. 4) based on Young (2009).

The CCAM and the SAAM, rather than relying on particular literature or scientific discipline, were grounded in the responses from key actors involved in the adoption process. Therefore, even if the qualitative-generated constructs are quantitatively analyzed in a posterior study, the inclusion of such constructs would be connected to the unique context in which the innovations are diffused. While the author of this dissertation recognizes that his worldview, experiences, and intrinsic interests influence not only analysis but also the results of this research, his sole intention in using the grounded theory methodology was the development of a model grounded in the data provided by the participants.

Quantifying the hypotheses suggested in the CCAM and SAAM models would increase the consistency of their comparison with other adoption studies. However, the inconsistencies in how constructs are treated in different models still pose challenges in generating coherent quantitative evidence to support these models. As Montes de Oca Munguia et al. (2021) suggest, such irregularities in how behavioral elements are approached in different models indicate that multiple interpretations of the same construct can arise. As a way of illustration, the CCAM and the SAAM identified that the construct "knowledge about an innovation" is fundamental for adopting clonal cacao and soil amendments by San Vicente's farmers. “Knowledge about innovation” has also been considered a relevant construct for understanding the adoption of new ideas and practices (Ainembabazi & Mugisha, 2014; Daniel et al., 2011). However, this concept of "knowledge" might be problematic as it can be expressed by more than one operational definition. As an illustration, for the concept of "farmer's knowledge about an innovation," Rogers (2003, p.172) describes three different types of knowledge. The first one is *awareness-knowledge*, which is nothing more than asking if a farmer knows about the existence of the innovations. The second type of knowledge about innovation is *how-to knowledge,* which consists of the information necessary to use it correctly. Finally, one could also ask about the *principles-knowledge*, which refers to the principles underlying how the innovation works. In this way, irregularities in the way researchers conceptualize and operationalize the constructs explaining adoption behaviors should be taken into consideration. In this way, the individual constructs identified in the CCAM and SAAM will be contrasted with both conceptual models explaining adoption and with empirical studies.

Donations

A factor that explained the adoption of clonal cacao and soil amendments in San Vicente was the "subsidies" that farmers received as direct incentives to encourage the adoption of these two innovations. In the case of soil amendments, participants reported that, mainly through projects, cacao farmers received bags of lime that were applied to their cacao plantations. Likewise, the research participants affirmed being beneficiaries of donations that encouraged the adoption of clonal cacao. In this case, farmers received cacao seeds, seedlings, or even workforce support without paying for it. Thus, according to participants, the "incentives" provided to farmers were connected to adopting both innovations.

Several adoption models consider the role of "incentives" in the adoption of innovations. Rogers' (2003) Diffusion theory sees incentives as essential to enhance the relative advantage of an innovation. In this way, monetary and nonmonetary incentives might accelerate the adoption of technologies. In some cases, as Rogers (2003) affirm, incentives are given to potential adopters to encourage the trial of a new idea. This previous situation was reported by participants from San Vicente, who confirmed that when the cacao clonal technology was introduced in the region, the seedlings were donated to farmers to facilitate trial use. Kuehne et al.'s (2017)

ADOPT model also considers "donations" as a significant influencer of the relative advantage of innovations. In particular, incentives reduce the investment cost, given the fact that the donations minimize the upfront cost of the actual innovation.

While the donations might be influential for an initial uptake of innovations, other adoption models suggest that they might not be relevant to explaining a sustained use of innovations. Satisfaction models, for instance, indicate that adopters' loyalty might not help explain adoption behaviors in situations where the innovations are not paid for by the adopters (Montes de Oca Munguia et al., 2021). The findings of this research support the previous affirmation as, in the case of soil amendments, some farmers did not continue their adoption even though they had used the innovation when subsidized. Interestingly, the former was not the case for the adoption of clonal cacao due to a significant difference between the characteristics of these two innovations. In the case of clonal cacao, its adoption is only taken, for each lot of the farm, on average, every 20-30 years. In contrast, farmers' decisions to adopt soil amendments must be taken every year. In this way, given the characteristics of clonal cacao, its adoption is more influenced by donations than it is by soil amendments.

Beliefs of using the innovation on farming objectives

Those cacao farmers who adopted clonal cacao and soil amendments did so because they believed that using these innovations was beneficial to accomplishing their farming objectives. However, it is necessary to note that this concept refers to the farmers’ perceptions of the innovation rather than its primary attributes. While the primary characteristics of innovation have been used as predictors in adoption studies, how farmers perceive using the innovations is what is relevant to explaining adoption behavior (G. Moore & Benbasat, 1991). Under those circumstances, understanding the adoption phenomena requires research focusing on a motivational and an affective level of analysis, such as it is the case of the Theory of Planned Behavior and the Technology Acceptance Models.

The Theory of Planned Behavior (TPB) emerged as a major framework for understanding, predicting, and changing human behavior (Ajzen, 2011). As Ajzen himself affirms, “behavior is performed not automatically or mindlessly but follows reasonably and consistently from the behavior-relevant information available to us.” (Ajzen, 2011, p. 438) In fact, the TPB is considered as an extension of the theory of reasoned action, which assumes that someone’s attitude towards some behavior is determined by how he/she assesses the results of such behavior. On the other hand, the Technology Acceptance Model by Davis (1986), technology adoption is explained by behavioral intention, which is affected by 1) the perceived usefulness of the technology and 2) its perceived ease of use. In order to increase the predictive ability of the TAM, additional variables have been added, which have result in additional TAM models (i.e., the TAM 3 by Venkatesh & Bala, 2008). Still, all the variations of the TAM and its predecessor, the TPB, are made up of concepts about the affective domain (attitudes, beliefs, perceptions).

Two additional concepts from the CCAM and the SAAM that belong to the affective domain are (1) the "perceived need to control Cd-and soil pH" for the SAAM and (2) the "perceived performance of the innovation." In the case of both concepts, adoption models that include attitudes and beliefs components support their relevance to the diffusion of innovations. Speaking of the construct "perceived performance of the innovation," its influence on adopting innovations by shaping "farmers' beliefs" can be linked to the TPB and satisfaction models. The satisfaction models analyzed by Montes de Oca Munguia et al. (2021), for instance, suggest that the "level of satisfaction with the innovation" ("perceived performance" in this research) leads to increased "loyalty" to the innovation (adoption) by influencing the "users' trust" on it ("beliefs"). For the concepts "perceived need to control Cd and pH" and its moderator "knowledge about the role of the innovation," their influence on the adoption of the agricultural technologies has also been supported by adoption models. The ADOPT model, for instance, emphasizes that "knowledge of the relative advantage" of the innovation is fundamental to explaining adoption.

The previously mentioned concepts from the CCAM and SAAM belonging to the affective domain are connected to the "relative advantage" of innovation, a construct widely cited in adoption studies (see Kapoor et al. (2014) for a compilation of studies using "relative advantage" on adoption research). This connection of one single construct with several concepts from the CCAM and SAAM was only possible given the broad scope of the "relative advantage" construct. It is relevant to mention that the researcher's decision to keep the concepts separated rather than to merge them into a single construct ("relative advantage") was, in fact, due to its broadness and lack of a clear, measurable definition. While theories should result from abstraction (Van Lange et al., 2011), the broadness of the "relative advantage" has put it in a place where a variety of specific and measurable concepts can be tossed. When Moore & Benbasat (1991) developed an instrument to measure the perceptions of adopting an information technology innovation, they found that "relative advantage" did not emerge as a factor at all. The previous situation explains why in the CCAM, there is a distinction between three different beliefs about using the clonal cacao. Making such a distinction also facilitates the comparison of the results against other theories. For instance, the concept "perceive ease of use" developed by Davis' (1986) TAM theory could be connected to the concept "beliefs of using clonal cacao on facilitating labor." Likewise, the TAM's concept of "perceived usefulness" could be related to the "beliefs of using clonal cacao towards farm productivity and cocoa beans quality." Still, given the extensive use of the "relative advantage" concept, it is relevant to highlight that both the CCAM and the SAAM highlight its importance in the adoption of clonal cacao and soil amendments among cacao farmers from San Vicente.

Farmers' perceived need to control Cd

Analyzing the consequences of Cd on the adoption of clonal cacao and soil amendments is at the core of this research. However, as participants affirmed, there is no overall understanding among farmers of what Cd is and how it might impact their livelihoods. Likewise, there is a lack of knowledge about potential solutions to this problem. In this way, participants' behaviors were not influenced by the Cd current regulations.

Among the cacao farmers that were aware of Cd, there was a lack of mutual understanding regarding the origin of Cd, its regulations, its consequences, and its mitigation strategies. The controversies around the objectives of Cd regulations found in this research are consistent with the results of Prieto (2020), who interviewed several stakeholders of the cacao sector in Colombia to assess their understanding of the Cd regulations. The results from Prieto (2020), similar to what this research found, indicate that those producers who are aware of the Cd regulations do not fully understand them.

Concerns about the consequences of Cd regulations in cacao products have sparked the development of several multi-agency partnerships in Latin America. A good illustration is the project "Cacao 2030-2050," in which seven countries[27] joined efforts to develop technological alternatives to manage Cd in cacao (Fontagro, n.d.). The Clima Low Cadmium project (Clima-

[27] Costa Rica, Panamá, Colombia, Ecuador, Perú, Germany, and Italy.

LoCa), implemented with research partners from Latin America and Europe and directed to tackle the Cd issue in Colombia, Ecuador, and Peru, is another example of a direct effort to deal with this problem (CIAT, 2020). Together with these cases, it is also possible to find development projects that incorporate Cd alleviation among one of their several objectives. This is the case of Mocca[28], a five-year initiative funded by the USDA-FAS that seeks to improve the livelihood of over 120,000 coffee and cacao farmers in six Latin American countries[29] (Mocca, 2020). The urgency of addressing the challenge of Cd in cacao has also been exposed in recent academic and outreach events, some of them coordinated in the framework of the projects previously described. However, even though several initiatives have been deployed to deal with the cadmium issue, the participants of this research were not aware of them.

Even though most of the interviews were conducted when official documents about this heavy metal were already published (i.e., Bravo et al., 2021), farmers were unaware of them. Likewise, although some farmers participated in research programs on Cd, the results of such investigations had not been communicated to them. The previous is consistent with Prieto's (2020, p.31) affirmation that, even though information about regulations was already available, it was not being effectively shared with producers, a situation that created confusion among them.

Despite ambiguity around the Cd issue, research participants affirmed they had not yet been affected by this issue. This situation was similar to what (Prieto, 2020) found. According to this previous author, given that the Cd regulations focus on chocolate products rather than cocoa beans, the impacts on cacao producers are intangible. However, the last does not seem to be the

[28] MOCCA stands for Maximizing Opportunities in Coffee and Cacao in the Americas.
[29] Guatemala, El Salvador, Honduras, Nicaragua, Ecuador, and Perú.

case for cacao farmers from Ecuador. As mentioned by a representative of Ecuador's National Association of Cocoa Exporters-ANECACAO, trade agreements are now being canceled, particularly those involving single-origin cocoa beans, a situation that is finally affecting the farmers who still don't have a feasible solution yet to implement (Miranda, 2020).

Personality Traits

Rogers' (2003) book, arguably one of the most comprehensive academic reports on the adoption of innovations, suggests four main elements in the diffusion of innovations. One of these four elements is the social system, which individuals make with specific characteristics. In this research, such features have been referred to as personality traits. A personality trait is "a relative stable, consisting, and enduring internal characteristics that are inferred from a pattern of behaviors, attitudes, feelings, and habits in the individual" (VandenBos, 2007).

The personality traits of cacao farmers helped explain the adoption of clonal cacao and soil amendments in San Vicente. This affirmation that the internal characteristics of individuals are relevant to understanding adoption behavior is at the core of one of the chapters of Roger's book. According to Rogers (2003, p.267), innovativeness, defined as "the degree to which an individual is relatively earlier in adopting new ideas than other members of a system," is normally distributed like many other human traits. Using the average time of adoption as an indicator of innovativeness and assuming that innovation spreads to all the potential adopters, Rogers created the well-known 'adoption curve' that classifies adopters into five categories. The first category includes the innovators, who are the first 2.5% of individuals of a system that adopt an innovation. The second category represents the early adopters (13.5% of the population), while the third includes the early majority (34% of the individuals in a social system). The fourth category consists of the late majority, 34% of the adopters, while the last class, the laggards, comprises 16% of the adopters. Ruf (2012) also referred to the Rogers curve by affirming that the initial adopters of rubber were innovators who took risks as they didn't know the characteristics of the crop or the market of rubber. The success of the earlier adopters was, according to Ruf (2012), critical to influencing the adoption of rubber by other farmers as the latter followed the former ones.

Despite the clarity about the role of "innovativeness" in the adoption of innovations, its use was not considered in this research. Two main reasons why the adoption time was not emphasized in this research across the interviews. As described in the specific context of both innovations, the introduction of clonal cacao and soil amendments occurred decades ago. Under these circumstances, it was difficult for participants to remember when they first heard about these innovations and when they decided to adopt them. Rogers (2003) reported this methodological issue and affirmed that one weakness of diffusion research is the dependence upon self-reported data. Still, the responses from participants indicated that the internal characteristics of farmers were essential to explaining adoption-related behaviors.

The conceptualization of farmers' responses into different personality traits was a complicated process. Thus, to classify the personality traits factors influencing the adoption of innovations among cacao farmers, Nuthall's (2009) book was used. In this way, the internal characteristics of farmers that influenced the adoption of clonal cacao were classified into two personality trait factors: Thoughtful creativity and conscientious planning (Nuthall, 2009).

According to Nuthall's (2009) definition of thoughtful creativity as a person's attitude to new ideas, this trait aligns with Roger's "innovativeness" description. In contrast, the trait of conscientiousness planning is not considered by Rogers (2003) as a relevant attribute of individuals to explain adoption behavior. However, according to the participants' responses, an essential factor explaining farmers' decisions to adopt clonal cacao and soil amendments was farmers' attitude toward seeing the cacao as a business. Participants affirmed that when a cacao farmer considers the crop a business, they constantly seek ways to improve. In this research, this previous attitude is connected to Nuthall's (2009) description of conscientiousness planning as, according to this author, when information about the innovation is communicated to farmers, those who score high on conscientiousness planning dig deeper to find out the innovations' advantages or disadvantages in their situations.

Conclusions

This Grounded Theory study permitted the development of the CCAM and the SAAM, which explain the adoption of clonal cacao and soil amendments among cacao farmers in San Vicente de Chucuri. Thanks to the Grounded Theory methodology, the CCAM, and the SAAM, rather than relying on particular literature or scientific discipline, were grounded in the responses from key actors involved in the adoption process, making the CCAM and the SAAM context-specific models. Grounded Theory features also made it a suitable methodology for understanding the adoption of the clonal cacao and soil amendments among cacao farmers from San Vicente. Grounded theory was also helpful in elucidating that the same adoption process does not explain the adoption of these two innovations. As presented in Figures 1 and 2, the factors influencing the adoption of these innovations in San Vicente are diverse and interconnected in complex ways. Likewise, as previously described, the adoption of agricultural innovations occurs in a dynamic context influenced by local and broader factors that also have complex interactions. In this way, Grounded Theory stands out as a relevant methodology to study the diffusion of innovations, especially in a situation where there was a lack of knowledge regarding the variables and variables relationships that intervened in the adoption process.

Several factors were found to influence the adoption of both innovations. However, the Cd issue, which is at the heart of this study, was irrelevant to explaining cacao farmers' adoption of clonal cacao and soil amendments. The findings of this research are summarized in Diagrams 1 (CCAM) and 2 (SAAM). Both diagrams serve as visual devices describing the relationships between concepts that explain adoption behaviors. The findings of this research, summarized in both diagrams, suggest the following generalizations:

- **Overall context:** he adoption of agricultural innovations among cacao farmers from San Vicente was influenced by socioeconomic and environmental conditions unique to this place and this cropping system
- **Specific context**: The adoption of clonal cacao and soil amendments among cacao farmers from San Vicente occurred in a particular context that uniquely influenced the diffusion of these innovations.
- **Donations**: The higher the incentives provided to farmers, the higher the adoption of clonal cacao and soil amendments. Being a member of a producers' organization influences access to projects, which helps explain donations. Access to AEAS was also relevant to explaining donations of inputs related to clonal cacao.
- **Access to AEAS**: The higher the farmers' access to AEAS and projects, the higher the donations related to clonal cacao given to farmers. Access to the services provided by

Fedecacao (the leading AEAS provider) was also critical in influencing farmers' beliefs about using clonal cacao. Contrary to clonal cacao, access to AEAS directly influenced cacao farmers' adoption of soil amendments in San Vicente.

- **Farmers' beliefs about using the innovation on farming objectives**: Farmers' beliefs about using both innovations on productivity correlate with their adoption. For clonal cacao, farmers' belief about using cacao clones to facilitate labor correlates with clonal cultivars' adoption. In the same way, farmers' beliefs about using cacao clones on cocoa beans quality are correlated to the adoption of clonal cultivars. Finally, access to resources moderates the relationship between farmers' beliefs about clonal cultivars of cacao and their adoption.
- **Personality traits**: Farmers' conscientiousness planning is correlated with the adoption of clonal cacao and soil amendments. However, farmers' thoughtful creativity is only correlated with the adoption of clonal cacao.
- **Knowledge about the role of innovations towards perceived needs:** Knowledge of the role of cacao cultivars and soil amendments on Cd alleviation moderates the relationships between farmers' perceived need to control Cd and the adoption of these innovations. For soil amendments, the relationship between the perceived need to control pH and its adoption is moderated by farmers' knowledge of the role of soil amendments on pH control.

The creation of the CCAM and the SAAM, while consistent with recent adoption publications, fills a gap in the literature. The results of this research also provide the foundations for further research as well as for the design and implementation of effective interventions using these technologies.

Limitations

Qualitative research is, by nature, subjective. Besides being the primary instrument for data collection and data analysis, qualitative researchers make decisions regarding what the research questions will be and who will answer them. This previous situation is particularly true for the present research as just one researcher conducted it. Perhaps nothing better captures the subjectivity of a qualitative study than this last point, the selection of participants. Qualitative researchers have two thoughts about sampling: theoretical sampling and purposive sampling (Savin-Baden & Howell-Major, 2013). In purposive sampling, contrary to probability sampling, the objective of qualitative researchers is to provide an in-depth description of the case being studied. The logic and power of purposeful sampling, according to Patton (2002), lie in selecting information-rich subjects for study. Under those circumstances, the researcher's biases are valuable for determining those information-rich cases that yield insights and in-depth understanding rather than empirical generalizations.

The main limitation of this research is the generalizability of the results to a larger population. It is important to note, though, that a series of strategies were implemented during the design, interpretation, and writing process to enhance the quality of the research. In particular, the methodological consistency, the selection of a heterogeneous sample of individuals, the reliance on the literature, the validation of the analysis, and a thick description of the results were among those practices followed by the researchers to improve the study's rigor. Likewise, a positionality statement (Annex 1) is included to clarify the researcher's position while the research was conducted. However, the unique approach of this qualitative research limits the generalizability of the results to all the cacao farmers from San Vicente.

Recommendations

The first recommendation aims to address the previously described limitation by conducting a follow-up quantitative study. Given the estimated size of the population of cacao farmers from San Vicente, collecting data from the entire population is not feasible. Therefore, to establish the broadest possible generalizations of the CCAM and SAAM results, it is necessary to collect data from a sample representing the population's variability. Then, by relying on a process of a random selection of participants, quantitative research can use probability sampling to represent a population's variability adequately. It is critical to note that to establish the generalizability of results, scholars may use a variety of techniques in addition to random sampling. In particular, researchers may rely on replication, triangulation, and theoretical sampling(Singleton & Straits, 2017, p.184). Given that theoretical sampling was at the core of this qualitative research and that the combination of qualitative and quantitative methodologies is a form of triangulation, conducting a follow-up quantitative study is recommended. In this way, to test the generalizability of the hypotheses generated in this qualitative study, a quantitative research with a larger representative sample is encouraged.

The next set of recommendations is directed at future efforts of program development. Although the CCAM and the SAAM proposed in this study are new models for understanding the adoption of clonal cacao and soil amendments among cacao farmers from San Vicente, the following lessons provide foundations for the design and implementation of social interventions in this municipality.

1. **Donations of clonal cacao:** Attention should be paid to farmers’ preferences regarding propagation methods before donations of planting material are given to them.

2. **Beliefs about using cacao on farming objectives:** programs should not only tell farmers about the benefits of clonal cacao but also focus on visually showing farmers the attributes of improved clonal cacao cultivars. In particular, programs should emphasize the benefits of clonal cacao toward farm productivity, facilitating labor, and cocoa bean quality.
3. **Donations of soil amendments:** Given the importance of the previous adoption of soil amendments, programs should prioritize the quality of the soil amendment to be donated rather than its price. Programs should also consider donations of soil amendments to farmers whose farms' soils are not acidic.
4. **Soil amendments and productivity:** Programs should teach farmers that soil amendments are not only useful to increase soil pH and that products different than limes are useful to enhance the soil properties, which in turn, improve cocoa productivity.
5. **AEAS and soil amendment providers:** Social interventions should target extensionists from AEAS institutions and soil amendment providers. Extensionists and providers should be aware of the multiple benefits of soil amendments besides increasing soil pH. They should also know the reasons behind the price differences and, through oral communication, share this information with farmers.

The final set of recommendations has three objectives. First, they seek to increase farmers' awareness about Cd. Second, suggestions on what role governments can take to reduce the impacts of Cd regulations on cacao farmers are provided. Finally, it is suggested what steps could individual cacao farmers could take.

Increasing farmers' awareness of Cd

Being honest and frank is the right way to convey the message regarding the potential impacts of Cd on cacao farmers. Programs need to be very clear in telling them what they already know and be sincere and admit that there are issues we still do not comprehend. It is essential to mention that the problems associated with Cd may affect cacao farmers in ways that are not yet clear. Likewise, farmers might not have heard about Cd at all. Under those circumstances, in addition to explaining to farmers the potential impacts of Cd, social programs may need to cover several facets of this issue. Relevant information that cacao farmers should know about Cd is presented next.

How will Cd affect the commercialization of cacao? Farmers should be aware that the commercialization of cocoa beans might be affected by the Cd issue. This is especially true if those beans are used to produce chocolate in countries with ongoing regulations. It is important to let farmers know about potential impacts on the commercialization side. Nonetheless, it is equally vital to tell them that the price paid for cocoa at the national level (Colombia) does not consider Cd levels

What are the mitigation strategies to the Cd issue in cacao and what are their implications for farmers? Farmers should be informed about the main strategies that have been proposed to deal with Cd. Likewise, farmers should be aware of the potential impacts derived from each practice. These strategies and their respective effects are described below.

- *Avoid high-risk areas for establishing plantations*. This strategy implies that farmers located in areas with high Cd should not establish new cacao plantations (Vanegas et al., 2018). In other words, farmers should be aware that they must select another crop if they would like to increase or replace their cropping area.

- *Lower levels of cadmium through post-harvest processing*. Farmers should know that ongoing research is trying to reduce Cd levels in cacao beans during fermentation (i.e., Vanderschueren et al., 2020). They should also be aware of some of the implications this practice might generate. Nonetheless, this recommendation might also benefit farmers as they will not have to be worried about the fermentation and drying process.
- *Minimize the uptake of cadmium by the cacao tree by adopting agricultural practices.* It is important to let farmers know that most of the strategies to deal with Cd are being designed to be implemented on the farm. Farmers should hear about the most important solutions being studied, such as the research conducted in soil management and cacao varieties (Meter et al., 2019). However, farmers must be aware that there is not a proven solution to the Cd issue. Likewise, these practices could affect how farmers operate their crops, and they should be aware of it.

What is cadmium, and what is it used for? Farmers need to know that Cd is one out of the hundred chemical elements that exist on earth. They also must be aware that, unlike nitrogen, phosphorous, potassium, calcium, etc., Cd is not an essential element of the cacao tree. Farmers must be told that people have used Cd primarily to produce rechargeable batteries and, to a lesser extent, reduce corrosion of steel components, televisions, and other relevant processes. However, farmers must also learn that Cd is an environmental hazard.

How Cd affects people's health? Farmers should be aware that Cd is an issue of human concern. This heavy metal can cause cancer, kidney failure, and other health complications. Such being the case, it is important that they recognize that human efforts to avoid Cd contamination in humans and their environment are relevant to society, including themselves.

How are people exposed to Cd? It is relevant that farmers realize that Cd exposure may occur through several sources. Particularly, by breathing cigarette smoke, being in a place where Cd is used or generated, or by drinking water and eating food containing this element. Such being the case, they must recognize that human efforts to avoid Cd contamination in humans and their environment are relevant to society, including them themselves.

How do governments act to reduce the risk of Cd intake? It is relevant that farmers realize that a crucial human exposure to Cd is through the food, as previously stated. Consequently, farmers should be aware that food safety authorities must regulate Cd content in food products to reduce its intake among people. Likewise, they should realize that the regulations cover, in addition to cocoa products, a myriad of food products and their derivates. Farmers should also know that this occurs everywhere, but some regions have more strict regulations than others. In this case, they should be aware that limits on Cd levels in chocolate have been set in countries like the USA (California), Australia, Argentina, New Zealand, Russia, and the European Union.

How does Cd get to the cacao beans? Farmers must know that cacao plants absorb Cd from the soil. Farmers should be told that the roots of the tree uptake this element, and then it is transported to the stems, the leaves, and the pods, including the mucilage and beans. Also, it should be mentioned that the content in leaves is recycled through the leaf litter. I should also make clear that the way Cd moves into the plant is still unclear.

Where is Cd coming from? Farmers should learn that the soil could be contaminated with Cd due to several reasons. Although it has been recognized the importance of mining and fertilizers as a source of Cd contamination, they should know that, in most cases, Cd comes from the rocks that originated the soil. It is also necessary to let farmers know that maps of Cd in soil have already been published (i.e., Argüello et al., 2019; Bravo, Leon-moreno, et al., 2021), and that the contents of this element are higher in cacao-producing countries in Latin America, including those for Colombia. Also, that specific regions in Santander, Boyaca, and Cundinamarca have higher Cd content in soil than others.

How to measure Cd? It is important to tell farmers that Cd can be measured in the soil, water, fertilizers, and plant tissues. However, they should be aware that measuring this element requires specific technology, which explains why most of the analyses are conducted in laboratories. It would also be relevant to let farmers know about the scale of measurement used when talking about Cd (ppm). Farmers should be told, for instance, that 2.0 ppm of Cd in soil could be translated as having 4 kg[30] distributed in one hectare. Or that 1 ton of cocoa beans with 2.0 ppm indicates that there are 2 grams of Cd in such an amount of beans.

What role can governments take to reduce the risks of vulnerable populations to the consequences of the accumulations of Cd in their beans?

- *Farmers in affected areas might receive lower prices.* Local, regional, and national governments play a crucial role in guaranteeing that the price of cocoa is not affected by the Cd content. In particular, the federal government must ensure that the price of cocoa depends, as it is today, on the international price and the quality of the beans, as defined by the Colombian Technical Norm (NTC) 1252. The regional and local governments must

[30] Assuming a bulk density of the soil of 1 g/cm^3 and a soil depth of 20 cm.

ensure that this mandate is met, particularly in those areas with high Cd content. Publishing daily prices of cacao on the web pages of such public institutions would be helpful.

- *Farmers in affected areas might have to seek new markets.* Through its export agency PROCOLOMBIA, the federal government could help farmers' cooperatives identify new markets for cacao beans with high Cd contents. This agency should work directly with the Colombian Agricultural Research Institute (Agrosavia), who poses the equipment required to measure the Cd level of the beans. By doing this, it would be possible to guarantee that the Cd levels do not exceed the limits required by the clients. For small farmers cooperatives, the government should finance the lab test needed to assess Cd levels in cacao beans and soils. By doing this, small farmers in need of soil analysis would be also benefited. The government can also play a key role in divulgating already existing tools allowing the calculation of Cd limits in cacao beans depending on the target market and product. A good example of this is the ChocoSAFE calculator (https://platform.climaloca.org/chocosafe).
- *Farmers might not have the inputs needed to begin a new crop.* Several factors of production should be considered before starting a new crop, such as capital, land, labor, and technology. Local, regional, and federal governments could play a key role in providing these factors to small farmers stepping out the cacao crop. Based on the new law of agricultural innovation, regional governments should provide the information needed by farmers (Proyecto de Ley No 04 de 2017, 2017). Through the Rural Agricultural Planning Unit (UPRA), the federal government could provide the guidelines to define, based on suitability maps, the most appropriate crops that small should consider. Farmers need to be informed about the risks and the technical and marketing options of alternative crops before they can take a decision

(Schroth & Ruf, 2014). Such being the case, the role of the government is essential for providing such information.

What steps could individual cacao farmers or the cacao farming region of San Vicente de Chucuri can take?

- *Determine the Cd content in cacao beans and soil.* The first step any farmer should take is to make sure the Cd levels on their farm. The recently released Cd map in Colombia showed a significant variability of Cd in San Vicente's soils (Bravo, Leon-moreno, et al., 2021). The previous results highlight the importance of knowing the Cd status of each farm. Because the correlation between Cd in soil and Cd in cacao beans may vary (Engbersen et al., 2019; Lewis et al., 2018), it is relevant to analyze both the cacao beans and the soil. Farmers must learn how to do the appropriate sampling for collecting the soil and the cacao pods. It is recommended to follow the soil sampling documented by Osorio & Casamitjana (2011), as the instructions, supported by images, make the guide simple to follow. The previous sampling strategy could be also applied for collecting the pods that should be fermented and dried separately. It should also emphasize that the soil analysis should not only focus on Cd. The soil sampling should also be analyzed for soil fertility. The previous will permit to identify solutions to Cd tailored to the conditions of the farm. In case the farmer finds high Cd levels in cacao beans, the next step would be recommended.
- *Control of soil acidity.* Research indicates that the soil pH affects the Cd absorption of cacao plants, for which the use of soil amendments has been studied (Argüello et al., 2019, 2020; Ramtahal et al., 2019; Zeng et al., 2020). Besides the potential benefits of Cd alleviation, this practice is recommended because its benefits in crop productivity are well known (Li et al.,

2019). Higher pH levels in soils will immobilize toxic aluminum (AL^{+3}) and iron (Fe^{+3}), will increase the availability of phosphorus, and incorporates calcium and magnesium (N. W. Osorio, 2014), among other potential benefits.

- *Control of micronutrient deficiencies.* Some micronutrient deficiencies enhance Cd accumulation in plants. The previous is the case of iron (Connolly et al., 2002; Nakanishi et al., 2006). Similarly, zinc effects in Cd alleviation have also been studied (Hanafi & Jomol Maria, 1998; F. Wu & Zhang, 2002). In both cases, iron and zinc deficiencies are more acute in soils with elevated pH levels. Interestingly, the variation of pH levels in San Vicente's soils is significant. In this municipality, contrasting pH levels of 4.4 and 6.8 have been found (Bravo & Benavides-Erazo, 2020). Therefore, for those cases in which pH levels are low, and when at lower levels, iron and zinc applications reduce Cd uptake by cacao plants. Farmers should also be aware that correcting micronutrient deficiencies is fundamental to increasing productivity (Graham, 2008).

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APPENDIX A: JOURNAL ARTICLES FROM SYSTEMATIC LITERATURE REVIEW

No	Title	Decision	Rationale	Abstract read?	Full article read?
1	Factors for adoption of artificial insemination technology in pig: evidence from small-scale pig production system.	Exclude	Not related to perennial crops. Focuses on animals	No	No
2	Grain legume seed systems for smallholder farmers: perspectives on successful innovations.	Exclude	Not related to perennial crops. Focuses on an annual crop	Yes	No
3	Strategies for improved yield and water use efficiency of lettuce (*Lactuca sativa* L.) through simplified soilless cultivation under semi-arid climate.	Exclude	Not related to perennial crops. Focuses on an annual crop	No	No
4	Fire risk perpetuates poverty and fire use among Amazonian smallholders.	Exclude	Not related to agriculture	No	No
5	Adoption and utilisation of Zai pits for improved farm productivity in drier upper Eastern Kenya.	Exclude	Not related to perennial crops. Focuses on an annual crop	Yes	No
6	Accelerating genetic gain in sugarcane breeding using genomic selection.	Exclude	Doesn't focus on farmers' adoption of innovations	Yes	No
7	Assessment of soil micronutrients from a mango based agroecology of Malihabad, Uttar Pradesh, India.	Exclude	Doesn't focus on farmers' adoption of innovations	No	No
8	What impact does the adoption of drought-tolerant maize for Africa have on the yield and poverty status of farmers in the arid region of Nigeria?	Exclude	Not related to perennial crops. Focuses on an annual crop	No	No
9	Beef cattle farmers behavior toward biosecurity.	Exclude	Not related to perennial crops. Focuses on animals	No	No
10	Soil management for smallholders: lessons from Kenya and Nepal.	Exclude	Not related to perennial crops	Yes	Yes
11	Strategies to increase adoption of animal vaccines by smallholder farmers with focus on neglected diseases and marginalized populations.	Exclude	Not related to perennial crops. Focuses on animals	No	No
12	Smallholders' practices of integrated agriculture aquaculture system in peri-urban and rural areas in Sub Saharan Africa.	Exclude	Not related to perennial crops. Focuses on animals	No	No
13	Multi-country investigation of factors influencing breeding decisions by smallholder dairy farmers in sub-Saharan Africa.	Exclude	Not related to perennial crops. Focuses on animals	No	No

14	Adoption of appropriate technologies among smallholder farmers in Kenya.	Exclude	Not related to perennial crops. Focuses on other ag. Practices	Yes	Yes
15	Adoption of sustainable agricultural practices and food security threats: effects of land tenure in Zambia.	Include	Relevant abstract	Yes	Yes
16	Households' aspirations for rural development through agriculture.	Exclude	Perennial crops are not covered	Yes	Yes
17	Farmer perceptions of plant-soil interactions can affect adoption of sustainable management practices in cocoa agroforests: a case study from Southeast Sulawesi.	Exclude	Adoption of innovations in cacao are covered. However, it is not quantified the adopters/non adopters. presented empirical results of multivariate analysis of technology adoption. Specifically, they do not (a) have samples including adopters and non-adopters	Yes	Yes
18	Farm types and farmer motivations to adapt: implications for design of sustainable agricultural interventions in the rubber plantations of South West China.	Exclude	Focused on farmers' willingness to adapt to external change, not in the adoption of innovations	Yes	Yes
19	Is the increase of scale in the tropics a pathway to smallholders? Dimension and ecological zone effect on the mixed crop-livestock farms.	Exclude	Not related to perennial crops. Focuses on livestock	Yes	No
20	Factors that influence adoption of integrated soil fertility and water management practices by smallholder farmers in the semi-arid areas of eastern Kenya.	Exclude	Not related to perennial crops. Focuses on other ag. Practices	Yes	No
21	Payments for pioneers? revisiting the role of external rewards for sustainable innovation under heterogeneous motivations.	Exclude	Not related to perennial crops. Focuses on silvopastoral practices	Yes	No
22	Adoption of agroforestry among smallholder farmers in Ratnagiri District of Maharashtra state.	Exclude	Adoption of agroforestry among farmers was described. However, the article did not present empirical results of multivariate analysis, so it is not possible to identify which variables are significant on explaining the adoption of the studied innovations	Yes	Yes
23	Impact of extension interventions in improving livelihood of dairy farmers of Nadia district of West Bengal, India.	Exclude	Not related to perennial crops. Focuses on livestock	No	No

24	Adoption of an improved bean seed variety and consumption of beans in rural Madagascar: evidence from a randomised control trial.	Exclude	Not related to perennial crops. Focuses on an annual crop	No	No
25	Determinants of Integrated Soil Fertility Management technologies adoption by smallholder farmers in the Chinyanja Triangle of Southern Africa.	Include	Includes agroforestry as one of the technologies. However, most of the innovations and production systems are not for perennials	Yes	Yes
26	Influence of different plant materials in combination with chicken manure on soil carbon and nitrogen contents and vegetable yield.	Exclude	Not related to perennial crops. Focuses on an annual crop (tomato)	Yes	No
27	Effect of flock size and ecological area in the technological level of dual-purpose cattle system from Ecuadorian tropics.	Exclude	Not related to perennial crops. Focuses on livestock	No	No
28	Factors affecting technology adoption in small community farmers in relation to reproductive events in tropical cattle raised under dual purpose systems.	Exclude	Not related to perennial crops. Focuses on livestock	No	No
29	Factors affecting adoption of improved rice varieties among rural farm households in Central Nepal.	Exclude	Not related to perennial crops. Focuses on an annual crop	No	No
30	Adoption of agricultural innovations: investigating current status and barriers to adoption of heat stress management in small ruminants in Jordan.	Exclude	Not related to perennial crops. Focuses on livestock	No	No
31	Smallholder experiences with dairy cattle crossbreeding in the tropics: from introduction to impact.	Exclude	Not related to perennial crops. Focuses on livestock	No	No
32	Conservation tillage of rainfed maize in semi-arid Zimbabwe: a review.	Exclude	Not related to perennial crops. Focuses on an annual crop	No	No
33	Some water management options and challenges in micro & water sheds of N-W tract of India.	Exclude	Not focused on agricultural innovations	Yes	No
34	The role of farming experience on the adoption of agricultural technologies: evidence from smallholder farmers in Uganda.	Include	Includes coffee, banana, and maize	Yes	Yes
35	Through the technology lens: the expansion of rubber and its implications in Montane Mainland Southeast Asia.	Exclude	Article does not focus on adoption of innovations	Yes	Yes
36	Awareness and adoption of improved cassava varieties and processing technologies in Nigeria.	Exclude	Not related to perennial crops. Focuses on an annual crop	No	No
37	Opportunities and constraints to legume diversification for sustainable maize production on smallholder farms in Malawi.	Exclude	Not related to perennial crops. Focuses on an annual crop	No	No

38	Portable sawmills and SFM in the Amazon.	Exclude	The article did not present empirical results of multivariate analysis so it is not possible to identify which variables are significant on explaining the adoption of the studied innovations	Yes	Yes
39	Adoption of the Tenera hybrid of oil palm (Elaeis guineensis Jacquin) among smallholder farmers in Cameroon.	Include	Relevant title	Yes	Yes
40	Agricultural innovations in small-scale farming systems of Sudano-Sahelian West Africa: some prerequisites for success.	Exclude	Focuses on agropastoral production systems	Yes	No
41	Carbon stock and sequestration potential of agroforestry systems in smallholder agroecosystems of sub-Saharan Africa: mechanisms for 'reducing emissions from deforestation and forest degradation' (REDD+).	Exclude	Article does not focus on adoption of innovations. The focus is on carbon sequestration	Yes	Yes
42	Climate change and food security: the role of biotechnology.	Exclude	Not focused on adoption of innovation in perennial crops	Yes	No
43	The adoption of rubber in Côte d'Ivoire: prices, copying effect, ecological and social change.	Include	Relevant title	Yes	Yes
44	Farm and socio-economic characteristics of smallholder milk producers and their influence on technology adoption in Central Mexico.	Exclude	Not related to perennial crops. Focuses on livestock	No	No
45	Analysis of communication and dissemination channels influencing the adoption of integrated soil fertility management in western Kenya.	Exclude	Not clear whether perennial crops are covered	Yes	No
46	Adoption of agroforestry systems by smallholders in Brazilian Amazon.	Exclude	The article only sampled adopters of agroforestry systems; therefore it is not possible to identify the factors that explained such adoption	Yes	Yes
47	Participatory evaluation of sustainable land use and technology adoption in two agroecosystems.	Exclude	Perennial crops are not covered. Included maize, tomato, and peppers	Yes	Yes
48	Integrated tree crops-ruminants systems in South East Asia: advances in productivity enhancement and environmental sustainability.	Exclude	The article does not present empirical results of multivariate analysis, so it is not possible to identify which variables are	Yes	Yes

			significant on explaining the adoption of the studied innovations		
49	Knowledge through participation: the triumphs and challenges of transferring Integrated Pest and Disease Management (IPDM) technology to cocoa farmers in Papua New Guinea.	Exclude	It is not possible to identify which variables are significant on explaining the adoption of the studied innovations	Yes	Yes
50	Enhancing integrated approaches in agricultural learning systems using experiences from agroforestry.	Exclude	Relevant abstract	Yes	Yes
51	Chapter four. Restoring soil fertility in sub-Sahara Africa.	Exclude	Not related to perennial crops	Yes	No
52	Social and ecological facets of pest management in Honduran subsistence agriculture: implications for IPM extension and natural resource management.	Exclude	Not related to perennial crops. Focuses on annual crops (maize)	Yes	No
53	Constraints to farmers' adoption of direct-seeding mulch-based cropping systems: a farm scale modeling approach applied to the mountainous slopes of Vietnam.	Exclude	Perennial crops are not covered. Included maize, rice and pig raising	Yes	Yes
54	Determination of the capacities of farmers to adopt quinoa grain (Chenopodium quinoa Willd.) as potential feedstuff.	Exclude	Focuses on quinoa as feedstuff for livestock	Yes	Yes
55	A review of soil fertility management communication in sub-Saharan Africa.	Exclude	Doesn't focus on farmers' adoption of innovations	Yes	No
56	Can voluntary sustainability standards incentivise smallholder adoption? - the case of rice.	Exclude	Not related to perennial crops. Focuses on rice	Yes	No
57	Dilemma of nitrogen management for future food security in sub-Saharan Africa - a review.	Exclude	A review, not empirical	No	No
58	Evaluating the effectiveness of fingerling stocking and ecological perspectives in enhancing fish harvest in a large tropical reservoir of Northern India.	Exclude	Not related to perennial crops. Focuses on fishery	No	No
59	Factors affecting technology choice behaviour of rubber smallholders: a case study in central Hainan, China.	Include	Identifies the variables influencing the adoption of technology in Rubber	Yes	Yes
60	Impact of the adoption of good agricultural practices on tea bush debilitation in two smallholding ranges in galle district Sri Lanka.	Exclude	Doesn't focus on identifying the factors explaining the adoption of innovations	Yes	No
61	Innovative and sustainable approaches for agricultural water management in the drylands of the developing world.	Exclude	Doesn't explain the adoption of innovations	Yes	No

62	Leucaena feeding systems in Argentina. II. current uses and future research priorities.	Exclude	Not related to the factors explaining the adoption of Leucaena	Yes	No
63	Macropropagation as an innovative technology: lessons and observations from projects in Cameroon.	Exclude	Not related to the factors explaining the adoption of Leucaena	Yes	No
64	Smallholder cocoa agroforestry systems; is increased yield worth the labour and capital inputs?	Exclude	The article did not present empirical results of multivariate analysis so it is not possible to identify which variables are significant on explaining the adoption of the studied innovations	Yes	No
65	Socio economic characteristics of cricket farmers in Lake Victoria region of Kenya.	Exclude	Not related to perennial crops. Focuses on annual crops (maize)	No	No
66	Socio-economic determinants and impact of adopting climate-smart Brachiaria grass among dairy farmers in eastern and western regions of Kenya.	Exclude	Brachiaria grass is considered as a perennial crop. However, the dairy production system is not a perennial crop	Yes	No
67	The adoption impact of wheat-chickpea double cropping on yield and farm income of smallholder farmers in Central Highlands of Ethiopia: the case of Becho district.	Exclude	Not related to perennial crops. Focuses on wheat and chickpea	Yes	No
68	The impact of demonstration plots on improved agricultural input purchase in Tanzania: implications for policy and practice.	Exclude	Not related to perennial crops. Focuses on maize in Tanzania	Yes	No
69	The impact of farming systems extension on Caribbean small-farm agriculture: the case of St Kitts and St Vincent.	Exclude	From 1997	Yes	No
70	Tissue culture banana (Musa spp.) for smallholder farmers: lessons learnt from East Africa.	Exclude	Article does not focus on adoption of innovations	Yes	No
71	What influences farmer's adoption lag for soil and water conservation practices? Evidence from sio-malaba malakisi river basin of Kenya and Uganda borders.	Include	Agroforestry is one of the innovations analyzed	Yes	Yes
72	Accounting for Spillovers in Assessing the Effectiveness of Video Messages to Improve Potato Seed Quality: Evidence from Uganda	Exclude	Not related to perennial crops. Focuses on Potato	No	No

73	The Status of Perception, Information Exposure and Knowledge of Soil Fertility among Small-Scale Farmers in Ghana, Kenya, Mali and Zambia	Exclude	Article does not focus on adoption of innovations. Focuses on perceptions	Yes	No
74	Changing Opinion, Knowledge, Skill and Behaviour of Vietnamese Shrimp Farmers by Using Serious Board Games	Exclude	Not related to perennial crops	No	No
75	New and Emerging Technologies: Teacher Needs, Adoption, Methods, and Student Engagement	Exclude	Article does not focus on adoption of agricultural innovations	No	No
76	Is There an App for That?: Describing Smartphone Availability and Educational Technology Adoption Level of Louisiana School-Based Agricultural Educators	Exclude	Article does not focus on adoption of agricultural innovations	No	No
77	Do Farm Advisory Services Improve Adoption of Rural Development Policies? An Empirical Analysis in GI Areas	Exclude	Research conducted in Italy, not in the tropics	Yes	No
78	Examining eXtension: Diffusion, Disruption, and Adoption among Iowa State University Extension and Outreach Professionals	Exclude	Does not focus on agricultural innovations	No	No
79	Adoption of Information and Communication Technologies (ICTs) by Agricultural Science and Extension Teachers in Abuja, Nigeria	Exclude	Does not focus on agricultural innovations	No	No
80	Factors Influencing New Entrant Dairy Farmer's Decision-Making Process around Technology Adoption	Exclude	Does not focus on perennial crops	No	No
81	Evaluation of Information and Communication Technology Utilization by Small Holder Banana Farmers in Gatanga District, Kenya	Include	Covers the adoption of tissue culture among banana farmers in Kenya	Yes	Yes
82	Factors Influencing Agricultural Leadership Students' Behavioral Intentions: Examining the Potential Use of Mobile Technology in Courses	Exclude	Does not focus on the adoption of agricultural innovations	No	No
83	Analysis of Communication and Dissemination Channels Influencing the Adoption of Integrated Soil Fertility Management in Western Kenya	Exclude	The adoption of innovations occurs in farming systems dominated by crop-livestock systems with the major food crop being maize.	Yes	Yes
84	Necessary, but Not Sufficient: Critiquing the Role of Information and Communication Technology in Putting Knowledge into Use	Exclude	Does not focus on the adoption of agricultural innovations	Yes	No

85	An Examination of the Strengths, Weaknesses, Opportunities, and Threats Associated with the Adoption of Moodle[TM] by eXtension	Exclude	Does not focus on the adoption of agricultural innovations	No	No
86	Land-Grant University Employee Perceptions of eXtension: A Baseline Descriptive Study	Exclude	Does not focus on the adoption of agricultural innovations	No	No
87	Impact of Crop Management Diagnostic Clinics on Advisors' Recommendations and Producer Practices	Exclude	Focuses on advisors' recommendations. Although includes producer practices, these producers are from the US, not small farm holders from tropical areas	Yes	No
88	The New Digital [St]age: Barriers to the Adoption and Adaptation of New Technologies to Deliver Extension Programming and How to Address Them	Exclude	Focuses US agricultural systems and it is not based on empirical data	Yes	No
89	Interactive Multimedia Instruction versus Traditional Training Programmes: Analysis of Their Effectiveness and Perception	Exclude	The differences in adoption of ag. Technologies across the three types of training program were not statistically analyzed	Yes	Yes
90	The Adoption Process of Ricefield-Based Fish Seed Production in Northwest Bangladesh: An Understanding through Quantitative and Qualitative Investigation	Exclude	Not related to perennial crops	Yes	No
91	A Behavioural Approach to Understanding Semi-Subsistence Farmers' Technology Adoption Decisions: The Case of Improved Paddy-Prawn System in Indonesia	Exclude	Not related to perennial crops	Yes	No
92	Learning Agriculture in Rural Areas: The Drivers of Knowledge Acquisition and Farming Practices by Rice Farmers in West Africa	Exclude	Not related to perennial crops	No	No
93	Fostering Effective Use of ICT in Agricultural Extension: Participant Responses to an Inaugural Technology Stewardship Training Program in Trinidad	Exclude	Measures intent to apply information and communication technologies, not on their adoption	Yes	No
94	From Adoption Potential to Transformative Learning around Conservation Agriculture	Exclude	Focuses on the development of a transformative learning process, so does not assess adoption behaviors	Yes	No

95	Agricultural Innovation Systems and Farm Technology Adoption: Findings from a Study of the Ghanaian Plantain Sector	Include	Studies the adoption of innovations among plantain farmers in Ghana	Yes	Yes
96	Farmers' Participation in Extension Programs and Technology Adoption in Rural Nepal: A Logistic Regression Analysis	Exclude	Focuses on technology adoption in annual crops (cereals)	Yes	Yes
97	Enhancing Extension Programs by Discussing Water Conservation Technology Adoption with Growers	Exclude	Identifies the barriers to adoption using qualitative research, so it is not possible to quantify differences between adopters and non-adopters	Yes	No
98	Student Perceptions Concerning Their Experience in a Flipped Undergraduate Capstone Course	Exclude	Does not focus on the adoption of agricultural innovations		No
99	Socio-Economic Factors Affecting Adoption of Modern Information and Communication Technology by Farmers in India: Analysis Using Multivariate Probit Model	Exclude	Focuses on the adoption of Information and communication technologies, not on agricultural innovations implemented in perennial crops	Yes	Yes
100	The Seductive Power of an Innovation: Enrolling Non-Conventional Actors in a Drip Irrigation Community in Morocco	Exclude	Does not provide information about adopters/non adopters	Yes	No
101	Technology Usage of Tennessee Agriculture Teachers	Exclude	Does not focus on the adoption of agricultural innovations among smallholder farmers from the tropics	No	No
102	Assessment of the Adoption of Agroforestry Technologies by Limited-Resource Farmers in North Carolina	Exclude	Does not focus on the actual adoption of agroforestry but on the knowledge about and willingness to adopt	Yes	No
103	Exploring the Use of Information Communication Technologies by Selected Caribbean Extension Officers	Exclude	Does not focus on the adoption of agricultural innovations among farmers	No	No
104	Testing Extension Services through AKAP Models	Exclude	Does not focus on tropical areas	Yes	No
105	How Programme Teams Progress Agricultural Innovation in the Australian Dairy Industry	Exclude	Focus on dairy	No	No
106	The Use of Rainfall Forecasts as a Decision Guide for Small-Scale Farming in Limpopo Province, South Africa	Exclude	This study is a case study with a small number of participants	Yes	No

			(n=12) that does not analyze adoption/rejection of ag. Innovations		
107	Quantifying the Effect of Discussion Group Membership on Technology Adoption and Farm Profit on Dairy Farms	Exclude	Article focuses on dairy	No	No
108	Disseminating Improved Practices: Are Volunteer Farmer Trainers Effective?	Exclude	Does not study the factors influencing the adoption of innovations	Yes	No
109	Is Extension Ready to Adopt Technology for Delivering Programs and Reaching New Audiences?	Exclude	Does not focus on the adoption of agricultural innovations among farmers	No	No
110	Fish Pond Aquaculture in Cameroon: A Field Survey of Determinants for Farmers' Adoption Behaviour	Exclude	Article focuses on fishery	No	No
111	Barriers and Coping Mechanisms Relating to Agroforestry Adoption by Smallholder Farmers in Zimbabwe	Exclude	Does not describe the factors explaining the adoption/rejection of agroforestry	Yes	No
112	Does Privatizing Advisory Services Guarantee Better Services? Evidence from Advisory Services Pertaining to Cocoa Certification in Côte d'Ivoire	Exclude	Does not focus on the adoption of agricultural innovations among farmers	Yes	No
113	Exploring Producer Innovation Adoption Using an Extension-Led Trialing Program	Exclude	Focuses on adoption of technology for the dairy sector in the US	Yes	No
114	A New Perspective on Adoption: Delivering Water Conservation Extension Programming to Nursery and Greenhouse Growers	Exclude	Focuses on adoption of technology for nurseries and greenhouses (non-perennials) in the US	Yes	No
115	Back to the Basics: Are Traditional Educational Methods Still Effective in a High-Tech World?	Exclude	Does not focus on the adoption of agricultural innovations among farmers from the tropics	Yes	No
116	Modifying the Farmer Field School Method to Support On-Farm Adaptation of Complex Rice Systems	Exclude	Focuses on rice	No	No
117	Using Adoption and Perceived Characteristics of Fertilizer Innovations to Identify Extension Educational Needs of Florida's Residential Audiences	Exclude	Does not focus on farmers	No	No
118	Communicating with 4-H Stakeholders: Examining Social Media Use in Rural and Urban Programs	Exclude	Focuses on the US 4-H program	No	No

119	Best-Bet Channels for Integrated Soil Fertility Management Communication and Dissemination along the Agricultural Product Value-Chain: A Comparison of Northern Ghana and Western Kenya	Exclude	Studies the adoption of innovations among maize farmers	Yes	Yes
120	Conversing about Citrus Greening: Extension's Role in Educating about Genetic Modification Science as a Solution	Exclude	Does not focus on farmers but consumers and does not study the adoption/rejection of innovations	Yes	No
121	Suitable for Whom? The Case of System of Rice Intensification in Tanzania	Exclude	Focuses on a non-perennial crop	No	No
122	Influence of Voluntary Coffee Certifications on Cooperatives' Advisory Services and Agricultural Practices of Smallholder Farmers in Costa Rica	Exclude	The article does not quantify the adoption of innovations	Yes	No
123	Adoption of Agri-Environmental Measures by Organic Farmers: The Role of Interpersonal Communication	Exclude	Studies the adoption of technology in Germany and it is not clear the specific crops studied	Yes	No
124	Over the Hurdles: Barriers to Social Media Use in Extension Offices	Exclude	Does not focus on adoption of innovations among farmers	No	No
125	Smallholder Information Sources and Communication Pathways for Cashew Production and Marketing in Tanzania: An Ex-Post Study in Tandahimba and Lindi Rural Districts, Southern Tanzania	Exclude	The article does statistically compare explanatory variables of adoption practices	Yes	Yes
126	Extension's Online Presence: Are Land-Grant Universities Promoting the Tripartite Mission?	Exclude	Focuses on the US Land-Grand system	No	No
127	Technology Acceptance Related to Second Life[TM], Social Networking, Twitter[TM], and Content Management Systems: Are Agricultural Students Ready, Willing, and Able?	Exclude	Focuses on students, no farmers	No	No
128	Using Information Technology to Forge Connections in an Extension Service Project	Exclude	Does not approach the adoption of ag. innovations	Yes	No
129	The Impact of Farmer Field Schools on Human and Social Capital: A Case Study from Ghana	Exclude	Focuses on experimentation, not on actual adoption of the practices. Additionally, there is no comparison on experimentation between farmers who participated in FFS and those who did not participate.	Yes	Yes

130	Information and Communication Technologies as Agricultural Extension Tools: A Survey among Farmers in West Macedonia, Greece	Exclude	Does not focus on tropical areas	No	No
131	School-Based Agricultural Education Teachers' Experiences during a Year-Long Field Test of the CASE Mechanical Systems in Agriculture (MSA) Curriculum	Exclude	Does not focus on the adoption of agricultural innovations among farmers	No	No
132	Participatory versus Traditional Agricultural Advisory Models for Training Farmers in Conservation Agriculture: A Comparative Analysis from Kenya	Exclude	The crops in which farmers work are not described, so it was not possible to say that the adoption of conservation ag. Occurred in a perennial system. Also, the adoption of agroforestry was not adopted in the paper	Yes	Yes
133	Using Hybrid Learning to Improve Educational Programs for Small-Acreage Farmers	Exclude	Does not focus on the adoption of agricultural innovations	yes	No
134	Actor Social Networks as Knowledge Sharing Mechanisms in Multi-Stakeholder Processes: A Case of Coffee Innovation Platforms of Uganda	Exclude	Does not focus on the adoption of agricultural innovations	yes	No
135	A Model for Understanding Decision-Making Related to Agriculture and Natural Resource Science and Technology	Exclude	Does not focus on the adoption of agricultural innovations	yes	No
136	A Novel Framework for Identifying the Interactions between Biophysical and Social Components of an Agricultural System: A Guide for Improving Wheat Production in Haryana, NW India	Exclude	Does not focus on the adoption of perennial crops' innovations	yes	No
137	Are All Young Farmers the Same? An Exploratory Analysis of On-Farm Innovation on Dairy and Drystock Farms in the Republic of Ireland	Exclude	Dairy industry in Ireland	No	No
138	Identifying the Needs of Opinion Leaders to Encourage Widespread Adoption of Water Conservation and Protection	Exclude	Does not focus on the adoption of innovations among farmers	No	No
139	Distributing and Showing Farmer Learning Videos in Bangladesh	Exclude	Does not measure adoption of ag. Innovations	Yes	No
140	Knowledge Gaps and Rural Development in Tajikistan: Agricultural Advisory Services as a Panacea?	Exclude	Does analyze the adoption of ag. Innovations	Yes	No
141	Opportunities and Best Practices to Support Sustainable Production for Small Growers and Post-Harvest Processors in Southern California	Exclude	Not from tropical regions	No	No

142	Co-Production of Knowledge in Multi-Stakeholder Processes: Analyzing Joint Experimentation as Social Learning	Exclude	Does not measure adoption of ag. Innovations	Yes	Yes
143	Interactions between Niche and Regime: An Analysis of Learning and Innovation Networks for Sustainable Agriculture across Europe	Exclude	Not from tropical regions and not focuses on farming practices	Yes	No
144	Small-Scale Farming in Semi-Arid Areas: Livelihood Dynamics between 1997 and 2010 in Laikipia, Kenya	Exclude	Does not focus on the adoption of ag. Innovations	Yes	Yes
145	Tea Time: Raising Awareness and Support for Extension	Exclude	Does not focus on the adoption of ag. Innovations	Yes	No
146	Experiential Learning Using Second Life[R]: A Content Analysis of Student Reflective Writing	Exclude	Does not focus on the adoption of ag. Innovations	No	No
147	Pursuing Knowledge and Innovation through Collective Actions. The Case of Young Farmers in Greece	Exclude	Not from tropical regions	No	No
148	Virtual Training for Virtual Success: Michigan State University Extension's Virtual Conference	Exclude	Not from tropical regions	No	No
149	The Relationship of Future Agricultural Extension Educators' Cognitive Styles and Change Strategies for Adult Learners	Exclude	Does not focus on the adoption of ag. Innovations	Yes	No
150	Effectiveness of Alternative Extension Methods through Radio Broadcasting in West Africa	Exclude	Focuses on the adoption of innovations among farmers of non-perennial crops (cowpea)	Yes	No
151	Creating Self-Reliance and Sustainable Livelihoods amongst Small-Scale Sugarcane Farmers	Exclude	Does not rely on empirical data on the adoption of innovations	Yes	No
152	Impacts of the COVID-19 Pandemic on Community Partners in the Agriculture Industry in Hawai'i	Exclude	Not related to the factors explaining the adoption of ag. Innovations	No	No
153	Impact of a Professional Development Experience Focused on Extension Educators as Change Agents	Exclude	Does not focus on farmers but extensionists	No	No
154	Fork2Farmer: Enabling Success of Small Farms through Partnerships with Well-Known Chefs and the Tourism Sector	Exclude	Focuses on the US food sector	Yes	No
155	On-Farm Forest Income in the United States, 2003-2012: Thoughts for Extension Programming	Exclude	Does not cover the adoption of ag. Innovations	No	No
156	Saving Citrus: Does the Next Generation See GM Science as a Solution?	Exclude	Focuses on the public, in the US	Yes	No
157	Perspectives of Extension Agents and Farmers toward Multifunctional Agriculture in the United States Corn Belt	Exclude	Research location is the US	No	No

158	Demand for Agricultural Extension Services among Small-Scale Maize Farmers: Micro-Level Evidence from Kenya	Exclude	The study aims to identify the factors that influence access to extension services. The main crop of the research location is maize	Yes	Yes
159	Transforming the Roles of a Public Extension Agency to Strengthen Innovation: Lessons from the National Agricultural Extension Project in Bangladesh	Exclude	Does not study the factors influencing the adoption of innovations	Yes	No
160	Expanding Cooperative Extension's Audience: Establishing a Relationship with Cowboy Church Members	Exclude	Focuses on the US	No	No
161	Small Farmers and Social Capital in Development Projects: Lessons from Failures in Argentina's Rural Periphery	Exclude	Does not study the factors influencing the adoption of innovations	Yes	No
162	Herd-Health Programs for Limited-Resource Farmers: Prevention versus Treatment	Exclude	Does not focus on perennial crops	No	No
163	The Uplands after Neoliberalism?--The Role of the Small Farm in Rural Sustainability	Exclude	Does not study the factors influencing the adoption of innovations. Research conducted in Scotland and in Norway	Yes	No
164	Public and Private Agri-Environmental Regulation in Post-Socialist Economies: Evidence from the Serbian Fresh Fruit and Vegetable Sector	Exclude	Does not study the factors influencing the adoption of innovations	Yes	No
165	Factors Influencing Adoption and Implementation of Cooking with Kids, an Experiential School-Based Nutrition Education Curriculum	Exclude	Does not study the factors influencing the adoption of innovations	No	No
166	Assessing the Long-Term Impacts of Water Quality Outreach and Education Efforts on Agricultural Landowners	Exclude	Location: Utah	Yes	No
167	The Influence of Enterprise Diversification on Household Food Security among Small-Scale Sugarcane Farmers: A Case Study of Muhoroni Division, Nyando District, Kenya	Exclude	Does not study the factors influencing the adoption of innovations	Yes	No
168	Can Schools Offer Solutions to Small-Scale Farmers in Africa? Analysis of the Socioeconomic Benefits of Primary School Agriculture in Uganda	Exclude	Does not study the factors influencing the adoption of innovations	Yes	No
169	Rural Women in Local Agrofood Production: Between Entrepreneurial Initiatives and Family Strategies. A Case Study in Greece	Exclude	Location: Greece	No	No

170	Cooperation with Commodity Groups and Hands-On Demonstrations Improve the Effectiveness of Commodity-Focused Educational Programs	Exclude	Studies wheat and soybean producers and does not focus on the adoption of innovation	Yes	No
171	Exploring Farmers' Decisions to Engage in Grass Measurement on Dairy Farms in Ireland	Exclude	Dairy farms in Ireland	No	No
172	Moving toward Sustainable Agriculture through a Better Understanding of Farmer Perceptions and Attitudes to Cope with Climate Change	Exclude	Does not quantify the adoption of innovations among adopters/non adopters	Yes	No
173	The Military Families Learning Network: A Model for Extension-Based Virtual Learning Communities	Exclude	Does not study adoption of agricultural innovations	Yes	No
174	The Potential for Developing Educational Farms: A SWOT Analysis from a Case Study	Exclude	Does not study adoption of agricultural innovations	Yes	No
175	Evaluation of Farmer Participatory Extension Programmes	Exclude	Does not study adoption of agricultural innovations	Yes	No
176	Privatisation of Agricultural Advisory Services and Consequences for the Dairy Farmers in the Mantaro Valley, Peru	Exclude	Focuses on dairy farms	No	No
177	Value-Added Dairy Products from Grass-Based Dairy Farms: A Case Study in Vermont	Exclude	Focuses on dairy farms	No	No
178	Developing the Capacity of Farmers to Understand and Apply Seasonal Climate Forecasts through Collaborative Learning Processes	Exclude	Does not study adoption of agricultural innovations	Yes	No
179	Fish Farm Challenge Provides STEM Design Experiences for Youth	Exclude	Focuses on fish farms	No	No
180	Factors Influencing Access to Integrated Soil Fertility Management Information and Knowledge and Its Uptake among Smallholder Farmers in Zimbabwe	Exclude	Farming system is maize with legume and crop-livestock interaction	Yes	Yes
181	Diffusion of Social Media among County 4-H Programs in Tennessee	Exclude	Location: Tennessee	No	No
182	Wood Energy Production, Sustainable Farming Livelihood and Multifunctionality in Finland	Exclude	Location: Finland	No	No
183	Entrepreneurial Checklist Tool for Beginning Farm and Home-Based Businesses	Exclude	Title not related to the adoption of innovations	No	No
184	Adapting Extension Food Safety Programming for Vegetable Growers to Accommodate Differences in Ethnicity, Farming Scale, and Other Individual Factors	Exclude	Focus on a non-perennial system and does not approach the adoption of innovations	No	No

185	Rural Community and Rural Resilience: What Is Important to Farmers in Keeping Their Country Towns Alive?	Exclude	Title does not reflect the adoption of innovations	No	No
186	Information Search Behaviors of Indian Farmers: Implications for Extension Services	Exclude	Title does not reflect the adoption of innovations	No	No
187	Local Farmers' Organisations: A Space for Peer-to-Peer Learning? The Case of Milk Collection Cooperatives in Morocco	Exclude	Focus on dairy	No	No
188	Can We Find Solutions with People? Participatory Action Research with Small Organic Producers in Andalusia	Exclude	Title does not reflect the adoption of innovations	No	No
189	The Environmental Belief Systems of Organic and Conventional Farmers: Evidence from Central-Southern England	Exclude	Location: England	No	No
190	Entrepreneurs and Producers: Identities of Finnish Farmers in 2001 and 2006	Exclude	Location: Finland	No	No
191	From the Researched to Co-Researchers: Including Excluded Participants in Community-Led Research on Urban Agriculture in Cape Town	Exclude	Title does not reflect the adoption of innovations	No	No
192	Adult Learning Theory Principles in Knowledge Exchange Networks among Maple Syrup Producers and Beekeepers in Maine	Exclude	Location: Maine	No	No
193	Effectiveness of Utilizing an Evidence Based Safety Curriculum to Increase Student Knowledge	Exclude	Does not focus on the adoption of ag. Innovations	No	No
194	Developing a Local Definition of Urban Agriculture: Context and Implications for a Rural State	Exclude	Title does not reflect the adoption of innovations among smallholder farmers from the tropics	No	No
195	Demand-Led Extension: A Gender Analysis of Attendance and Key Crops	Exclude	Does not focus on the adoption of ag. Innovations	No	No
196	Why Do Information Gaps Persist in African Smallholder Agriculture? Perspectives from Farmers Lacking Exposure to Conservation Agriculture	Exclude	Does not focus on the adoption of ag. Innovations	Yes	No
197	Multi-Stakeholder Process Strengthens Agricultural Innovations and Sustainable Livelihoods of Farmers in Southern Nigeria	Exclude	Does not focus on the adoption of ag. Innovations	Yes	No
198	A Quantitative Assessment of an Outsourced Agricultural Extension Service in the Umzimkhulu District of KwaZulu-Natal, South Africa	Exclude	Does not focus on the adoption of ag. Innovations	Yes	No

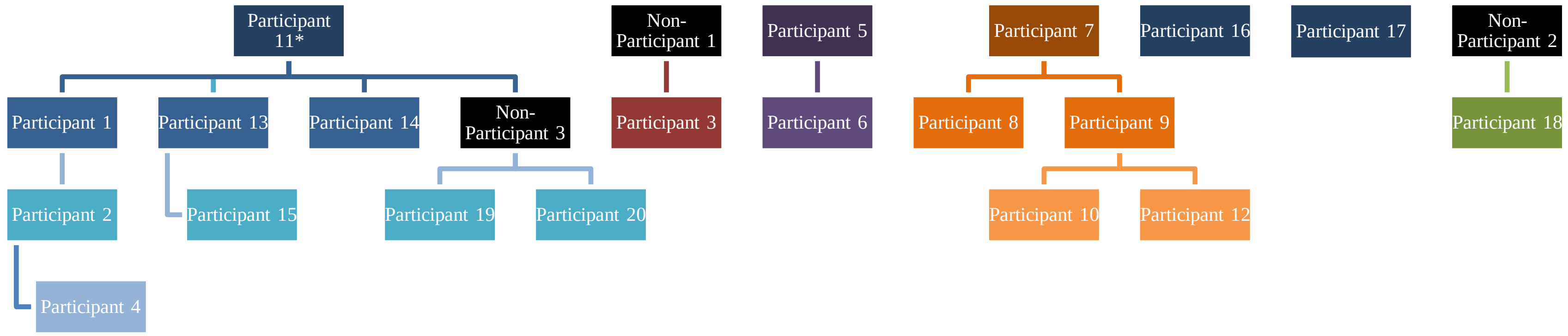
199	Meeting Stakeholder Energy Technology Education Needs Using a Mobile Demonstration	Exclude	Does not focus on the adoption of ag. Innovations	No	No
200	Networked Learning for Agricultural Extension: A Framework for Analysis and Two Cases	Exclude	Title does not reflect the adoption of innovations among smallholder farmers from the tropics	No	No
201	Third Thursday Thing: A Success Story for Reaching Underserved Clients	Exclude	Does not focus on the adoption of ag. Innovations	No	No
202	In the Field: Increasing Undergraduate Students' Awareness of Extension through a Blended Project-Based Multimedia Production Course	Exclude	Does not focus on the adoption of ag. Innovations	No	No
203	Adapting an Outcome-Based Education Development Process to Meet Near Real-Time Challenges to Sustainable Agricultural Production	Exclude	Location: Oregon	Yes	No
204	Going the Distance Part 2: Five Ways of Teaching an Extension Course: Elive, Blackboard, Teleconference, Correspondence, and Face-to-Face	Exclude	Does not focus on the adoption of ag. Innovations	No	No
205	Bringing "Invisible" Side Activities to Light. A Case Study of Rural Female Entrepreneurs in the Veenkolonien, the Netherlands	Exclude	Location: the Netherlands	No	No
206	Fair Trade: Social Regulation in Global Food Markets	Exclude	Does not focus on the adoption of ag. Innovations	No	No
207	Vulnerability to Bushfires in Rural Australia: A Case Study from East Gippsland, Victoria	Exclude	Does not focus on the adoption of ag. Innovations	No	No
208	"Profits to the Danes, for Us--Hog Stench?" The Campaign against Danish Swine CAFOs in Rural Lithuania	Exclude	Location	No	No
209	Education Needs of Michigan Farmers	Exclude	Location	No	No

APPENDIX B: DATA COLLECTION/ANALYSIS CHRONOGRAM.

Date	Activity
• 04/09/2020	Interview P1
• 04/10/2020	Interview P2
• 04/13/2020	Interview P3
• 04/14/2020	Interview P4
• 09/17-20/2021	First round of data analysis: concepts and their relationship were created. Identification of new participants.
• 09/21/2021	Interview P5
• 09/22/2021	Data analysis: new concepts and their relationship were created. Already created concepts/relationships were developed. Diagram 1 created. Hand-drawn. Diagram 2 created. Hand-drawn. Identification of new participants.
• 09/24/2021	Interview P6 Data analysis Diagram 3: Soil Amendments. Created using the tool Creately. Diagram 3: Clonal Cultivars using Creately.
• 10/05/2021	Interview P7
• 10/06/2021	Interview P8
• 10/07/2021	Interview P9
• 10/08/2021	Interview P10 Data analysis
• 11/02/2021	Interview P11
• 11/03/2021	Interview P12
• 11/02/2021	Interview P13 Data analysis
• 11/04/2021	Interview P14
• 11/05/2021	Interview P15
• 11/05/2021	Interview P16 Data analysis Diagram 4 Soil Amendment Diagram 4 Clonal Cultivars
• 11/09/2021	Communication with P17 Data analysis Final diagram Soil Amendment (Diagram A: Soil Amendments)

- 11/15/2021 Interview P18
  Data analysis
  Final diagram Clonal Cultivars
- 11/16/2021 Member checking of final diagram Soil Amendment with P08
- 11/18/2021 Interview P19 Part A
  Data analysis
- 11/19/2021 Interview P19 Part B
  Interview P20
  Data analysis
  Final diagram of Soil amendments updated (version B)
- 11/29/2021 Member checking of final diagrams (Soil Amendment version B and Clonal Cultivars version A) with P05
  Data analysis
- 12/02/2021 Member checking of final diagrams with P01
  Data analysis
- 01/22/2022 Member checking of final diagrams with P06
  Member checking of final diagrams with P19
  Data analysis

APPENDIX C: IDENTIFICATION OF RESEARCH SUBJECTS



* Participant 11 was not viewed as a research subject at the beginning of this research. However, his participation in this research was considered relevant after the initial data analysis.

APPENDIX D: INTERVIEW QUESTIONS' EVOLUTION BASED ON THEORETICAL SAMPLING

This document shows how the interview questions asked to participants evolved throughout the research. The document illustrates the interview questions asked to participants as well as the ideas that generated such questions. This Annex is comprised of nine documents created by the researcher while analyzing data. Line separators are used to distinguish individual documents.

The initial questionnaire, used from April 9-14 of 2020 to interview participants 1-4, contains questions that were generated without preliminary data analysis. The following eight documents were the result of the theoretical sampling method. Each document was created using notes from the memos, the written record of the data analysis, and from the notes taken during the elaboration of diagrams.

Within the memos, the researcher identified concepts and concept relationships that needed to be further developed. In such cases, the researcher used blue ink to visually differentiate the questions that needed to be asked to participants to develop mentioned concepts. All the memos were written in the software NVivo. In contrast, the documents containing the interview questions and the memo's fragments that generated such questions were in separate Word documents. These latter documents are presented in this Annex. Each document includes the date and the participant(s) to whom the questions were asked.

In some cases, the documents also include, enclosed in quotes, the name of the concepts. All the questions were grouped on similar topics (i.e., all the questions related to the adoption of soil amendments were together). Until October 22, 2021, the documents did not specify the specific questions asked to participants (see documents 2-5 in this Annex). Thereinafter, specific interview questions were included in the documents.

As part of the theoretical sampling process, the researcher realized that it was necessary to develop the concepts further to interview participants other than cacao farmers. In such cases, separate questionnaires were developed to interview soil amendment providers and experts, cacao extensionists, and farmers.

Document 1
April 9-14, 2020.
Interview questionnaire used for the telephone interviews with participants 1-4

1. If I followed you through a typical day, what would I see you doing? Livelihood activities
   Probing questions
   - Do you have an out of farm work?
   - In addition to cacao, which other crops do you have? Livestock?
   - Cacao practices
   - Fertilization
   - Weed control
   - Liming
   - Pruning
   - Harvesting
2. How did you start cultivating cacao?
   Probing questions
   - Did you grow up in a cacao farm?
   - How many generations of your family have farmed cacao?
3. How satisfied are you cultivating cacao?
   a. What do you like?
   b. What don't you like?
   Probing questions
   - Do you think it is a profitable crop?
   - How much time do you invest?
4. What do you think about replacing (substitute) the cacao trees?
   a. Using other crops, you already have in the farm?
   b. Using crops, the ones recommended by the government?
   Probing questions
   - What about: increasing revenues?
   - stabilizing income?
   - maintain food security, or reducing risk?
5. Based on your previous answer, what are the main objectives for substituting or not the cacao crop?
6. How do you feel about being a farmer?
   a. About being a cacao-farmer?
7. What are in your opinion the most important threatens to the cacao crop?
8. Have you heard about heavy metals in cacao? About cadmium?
9. What is your opinion about cadmium in cacao?

Other Probing questions:

- Could you repeat me, please?
- What do you want to say exactly?
- Could you give me more details on that, please?

Other questions:

- What is your gender?
- What is your age?
- What is your level of formal education?
- Farm size
- What is your annual net income from your farm?
    - Do you or someone in your household have off-farm income?
    - Income due to cacao

Document 2
Sept 17-20, 2021

Theoretical sampling process before interviewing participant No 5

- “Not an average farmer”
    - I want to know if farmers perceive themselves as doing things "different" compared to the "average" farmer. Why? because this "belief" might have something to do with the "adoption of innovations." I could ask farmers about this, unless more relevant things pop up.
- “Livelihood Strategy”
    - To further develop the concept of "livelihood strategies", I will need to talk to a farmer with a lower level of diversification.
- “Innovation characteristics”
    - My point here is that the farmer did not recognize fertilization as a practice from the beginning. It would be interesting to compare if other farmers do the same.
    - I need to ask other participants if they consider "fertilization" and specifically "liming" as a "complementary" or "rutinary" practice, or just a different practice compared to others required in a cacao farm. Note that another common practice, pruning, was not mentioned within the initial "rutinary" practices. Therefore, I have to ask farmers how they consider these practices as being different.
- “Knowing soil characteristics”
    - As the pH is just one characteristic of the soil, it would be interesting to know if farmers "know" about other characteristics, such as the organic matter content, the texture (relevant for liming), the Al content, and the levels of N-P-K-Mg, etc.
- Relationship between “dv soil analysis and fertilization” and other “IVs”
    - *DV: soil analysis and fertilization*
        - There is a response from P1 that I consider important to understand what explains the adoption of innovations, in particular, the decision of doing soil analysis and fertilization. Note: for next participants I need to separate

both things. One can have a soil analysis and not fertilize, or the opposite. Likewise, one thing is the fertilizing with NPK nutrients and another one is with lime.

- *"IVs of Adopting Soil Analysis and Fertilization"*
    - I think that the way I'm asking these questions is not adequate. Hereinafter I'm going to ask:
        1. Do you know if your soil is acid?
        2. How do you know that?
        3. Do you know what are the consequences of such acidity?
        4. Do you know how to increase the soil pH?
        5. Have you used lime?
        6. Do you know what are the benefits of applying lime? This is a question about "knowing about the relative advantage"
        7. Have you heard about lime to increase soil pH?
        8. I'm not sure what exactly is a soil corrective. I must ask to new participants if they differentiate soil correctives from lime.

        Note that the previous questions are connected to some concepts ("knowing innovations' dynamics") and relationships ("adoption DVs and knowing innovations' dynamics").
- *IV Soil characteristics*
    - *Farmers with "good soils" do not adopt soil analysis nor fertilization practices.* The logic of this hypothesis, in my opinion, is that if a farmer has good soils, the cacao plants will grow ok, and the farmer won't feel the necessity to do a soil analysis not to fertilize. Here it is necessary to ask farmers about this hypothesis. I could ask them whether they do have soil analysis and implement fertilization practices and if they believe that they do it (or not) because their soils are "not good" (or good).

- Adopting cacao varieties
    - Why do farmers take the decision to adopt a new cacao variety? Some ideas could be: 1) the farmer is about to start a new plantation, 2) the farmer is going to renovate a plantation, 3) the farmer is planting trees in the middle of an already established plantation, 4) the farmer is renovating the aerial part of an already established plantation).
    - But again, what motivates or restrict the farmer to take the decision to renovate? is it the productivity of the plantation? the age (connected to productivity)? the influence of diseases (connected to productivity or costs of production)? the age of the farmer?
    - All these are interesting questions that I could ask to new participants.
    -
- Relationship between "adopting cacao varieties" and "bean size"
    - Why are farmers interested in bigger beans?
- Relationship between "adopting cacao varieties" and "elevation"
    - Based on this response, one could think that the pressure of a disease could be a factor that would influence the adoption of a new cacao variety. Therefore, asking

about the concept "pressure of diseases" and its connection with the decision to adopt a new variety would be interesting.

- "Knowing innovation's dynamics"
    - To clarify more this doubts I must ask participants if they apply or not the practices I'm interested on. If they do apply them, ask the participants why; their motivations to do so. If not, ask them if they know about them (awareness-knowledge). The next questions could apply for both the participants who respond they adopt the innovations or that they are aware about it. I could ask them if they know how to use it (how-to knowledge); if so, ask for some principles (unsure about this question, although I'm now thinking that this principle-knowledge question is about the "needs/problems" farmers could face and the role of the innovations). After the how-to knowledge question, I could ask if farmers know about the problem the innovation is aimed to tackle (this is the need/problem) and about their knowledge of the role the innovation could play there.
- "Having the culture"
    - Is not "having the culture" not having used the innovation? This is an interesting question that I could ask to begin developing this concept.

Document 3
September 22, 2021
Notes took during elaboration of Diagram 1 and 2

I want to begin this interview asking first about the fundamental question that I have. I will ask the farmers about the why of adopting cacao varieties and liming.

- Practices on a typical day
    - Questions about "knowing crop system dynamics/knowing the need of the innovation"
        - From the note on the concept "Adoption decision" of "soil-related innovations": As a conclusion, I must ask about these "soil-related innovations" separately.
            - Soil analysis
            - Fertilizing with NPK
            - Liming
    - Intended to understand the "innovations characteristics" (frequency and stage)
- "Farm characteristics"
    - Area
    - Area in crops
        - Cacao, others
        - Area in cacao with hybrids
        - Area in cacao with clones
    - Age of crops (each lot)
- "Working Objectives"

- one of the properties that I have identified within this concept is" increasing profit." This is because I have not asked that much about the deepest intentions behind farming, questions that I must ask. Based on Ruf's framework, other "objectives" are to stabilize incomes, reducing risk, and maintaining food security. I also believe it would be important to ask whether farmers want to "maintain profits".
    - Why do you plant cacao?

- "Livelihood Strategy"
  - Thinking about the formula of the Break Even Point (Punto de Equilibrio in Spanish) allowed me to identify other potential properties of the concept "livelihood strategies". I think that other strategies could be to 1) reduce costs of production and 2) increase price of sold products. I noticed that both strategies might have some connection to the adoption of innovations. For instance, in order to reduce costs of production a farmer might not adopt lime. Or, in order to increase the price of the cacao, a farmer might adopt certain variety of cacao. Although this are just my ideas (are not fully supported in the data), I think it might be interesting to ask whether these two strategies are implemented by farmers and how they relate to the adoption of innovations I'm interested on.
- "Knowing crop system dynamics"
  - There is one thing that I'm unsure about and that I think is relevant for all the concepts concerned with "knowing". Is this "knowledge" the ones that explain the adoption of innovations? or once the farmer adopts an innovation seeks an explanation that support such behavior? How did you realize that you had to do this practice? relevant question to understand motivators. This question would be helpful to better understand this connection between "knowing" and "adopting". An ideal situation would be to ask P1: when did you start fertilizing? How did you realize that you had to do this practice? What motivates you to do it? did you do it because you learned about the nutrient cycle first? It would be also helpful to know whether this knowledge is all about "knowing the need for an innovation", which would be another name for this concept. Building on this comment, I believe that I should ask farmers everything related to the innovations of interest.
    - Have you heard about this practice?
    - Who told you about it?
    - When did they adopted them for first time?
    - Why did you do it? motivations
    - Currently, how many times per year do you apply this practice? In the case of cacao varieties, in what percentage of your farm have you adopted the practice?
    - How did you realize that you had to do this practice?
    - What motivates you to do it? What is your rationale for practicing it?
    - Do you believe that adopting this innovation helps you to accomplish the objective of increasing production?
    - how many people they know adopt it?
- "Liming" vs "fertilizing"

  - What is for you the main difference between liming and fertilizing/
- Note that I also need to ask about the soil analysis as a way to "know" the soil characteristics and see whether this "knowledge" influences the adoption of lime-fertilizers.

Document 4
September 24, 2021
Theoretical sampling process before interviewing participant No 6. Notes took during elaboration of Diagrams 3

- General
  - Concepts that need further clarification:
    - "Believing the innovation's influence on WO" and "Knowing innovations' role in the crop"
  - Believing the innovations' influences towards accomplishing the working objective
    - To further develop this concept, I should ask farmers why they do adopt and dedicate specific time to an innovation and not to others. I should also ask, first, for the working objective and then, for their beliefs that certain practices (the ones adopted and those rejected) are relevant to accomplish these objectives.
  - "Knowing innovations' role in the crop system" AND "Believing the innovations' influences" AND "Adopting"
    - To further develop this concept (knowing innovations. Role's), I believe that the ideal situation would be to identify all the "farmers' knowledge" about the innovations they adopt. To narrow it down to this research's interests, I will only focus on the innovations I'm interested on, including fertilization, soil analysis, rootstocks, and grafting.
    - Relevant questions to develop this concept could be: have you heard about these innovations (X, Y, Z)? Do you know what are the objectives of practicing these innovations? how did you know that? Note that these questions are connected to the "adopting" questions: do you adopt these innovations? How often? when was the last time you adopted it? how many times did you adopted it in the last year? and the questions related to "believing the innov. roles towards WOs), such as: why do you adopt/do not adopt these practices? what would happen if you do not adopt/adopt them?
  - "Having the culture"
    - This leads me to think that the "culture" could even come from previous generations. I think that it would be relevant to ask what the cropping systems of previous generations were. Some questions I could ask are:
      - When did you start to work with cacao?

        - Were your previous generation working with other crops? coffee?
        - What practices are you doing now to the cacao that you didn't do to the coffee?
        - Did you apply lime/fertilizer to the coffee?
    - Is not "having the culture" not having used the innovation? This is an interesting question that I could ask to begin developing this concept. I could ask: Do you think you have the culture of...? What is for you having the culture?
- "Price- paid by the farmer"
  - Note that I'm going to create a connection between this concept "price paid by the farmer" and the "adoption decision". This relationship will also include the concept "price-market". It is relevant to ask whether the farmer pays for the innovations of interest and which percentage.
- "Adoption decision" AND "Price paid by the farmer"
  - I'm wondering how many farmers that report to adopt an innovation (i.e., cacao clones) have done so through a project. It would also be interesting to know if they have continued to adopt the innovation.
- Liming
  - Liming on productivity
    - Ask whether farmers believe that liming influences the working objective
  - "Innovations' characteristics" (general); "frequency of adoption"
    - My point here is that the farmer did not recognize fertilization as a practice from the beginning. It would be interesting to compare if other farmers do the same.
    - I need to ask other participants if they consider "fertilization" and specifically "liming" as a "complementary" or "rutinary" practice, or just a different practice compared to others required in a cacao farm. Note that another common practice, pruning, was not mentioned within the initial "rutinary" practices. Therefore, I must ask farmers how they consider these practices as being different.
    - I also must ask the number of times/years they adopt these soil-related practices. Again, the focus is on "liming", however, I want to know the differences between "liming" and "fertilizing". I also should ask for the last time they adopted these practices.
    - It is important to note that here I'm missing several relevant practices (technologies). Particularly, all the practices required to establish a cacao crop. Within these practices is the selection of planting material, decision which is at the core of my research. I can still ask, though, how often do they adopt a new variety, which could be through 1) malayo, or 2) seedlings.
  - R- "Liming on Productivity" and "Price-Market"
    - It would be useful to compare the prices/kg of lime vs other fertilizers, including sulphates and silicate. Also, ask to farmers if they know the price of lime, NPK fertilizers, and organic fertilizers. Then, ask them their

thoughts about the connection between the price and their beliefs on the product's influence on achieving the WO.

    - "Availability" of lime
        - Why is there less availability of liming materials? Is it because the farmer does not use them, so the sellers do not offer them? I should talk to experts on liming and to sellers in San Vicente.
- Cacao varieties
    - Relationship between "adopting cacao varieties" and "pressure of disease" because of "elevation".
        - Based on this response, one could think that the pressure of a disease could be a factor that would influence the adoption of a new cacao variety. Therefore, asking about the concept "pressure of diseases" and its connection with the decision to adopt a new variety would be interesting.
    - Cacao varieties (seed/rootstock, and scion) on productivity.
        - Ask whether farmers believe that liming influences the working objective
- Cadmium
    - "Knowing robustness of cacao traceability"
        - To further develop this concept on "knowing robustness of cacao traceability", I should ask farmers if they know how robust the traceability system of their produce is.

Document 5

October 04, 2021

Theoretical sampling process after data analysis from participant No 6 and before interviewing Participants 7-10.

    - "Believing the innovation's influence on WO" and "Knowing innovations' role in the crop"
    - "Knowing Needs and Problems"
        - I should ask farmers how they perceive their current status, based on the WO I've identified so far. If someone perceives there is a big gap (a need) between what he/she is producing and what he/she wants to produce, it is likely that that need influences the adoption of technology. Note that this is the factor that P8 indicated to me. In the case of P6, he mentions that "there is a need to renovate the plants". I should have asked; how do you know that? what explains that?
    - "Perceived crop performance"
        - I consider it relevant to develop this concept of "crop performance". The "crop performance" is relative, hence I believe the right term to use should be "perceived crop performance". I should ask farmers how they perceive

their crop performance, and how such perception influences the adoption decisions of soil amendments and cacao varieties.

- Believing the innovations' influences towards accomplishing the working objective
- "Knowing innovations' role in the crop system" AND "Believing the innovs' influences" AND "Adopting"
- "Having the culture"
- "Adoption decision" AND "Price paid by the farmer"
    - Question for soil analysis: based on the connection between "Liming" and "Soil analysis" I will be asking several questions on soil analysis. I should include there the question of "who paid for the soil analysis you have?"
    - It is relevant to ask if farmers, based on the amount of soil amendment received, decide to apply it to the whole farm rather than just on the intended area. The same could happen when farmers are the ones who buy the products.
- "Price paid by farmer" AND "membership in an organization"
    - To further develop this relationship between price paid by farmers and membership in an organization, I should ask farmers whether their involvement in an organization determines the price paid for an innovations (in some cases, this value is zero).
- DV "Access to projects" AND "Membership in an organization".
    - It is also important to make the connection on how being a member of an organization helps to accessing projects and its benefits. Note, that based on my experience, some organizations are created because the project requires it. I also noticed, based on P6's comment, that the participation in a cooperative might also influence the technical assistance received by farmers. It would be important, then, to check whether participation in a cooperative influence the technical assistance received by a farmer.
- "Waiting for a subsidy"
    - "Waiting for a subsidy" is a concept that needs further development. I see the dimensions of this concept as a Likert scale measuring the level of expectancy for a subsidy (from high to low). To do so, I should talk to farmers who had been beneficiated by projects and those who have not. It would be interesting to see whether those farmers who have been beneficiated by projects are still expecting further subsidies to keep adopting.

- Liming
    - "Knowing soil amendment characteristics"
        - Even though the "mesh size" and "purity" of a soil amendment are "innovations' characteristics" that have not been mentioned by the farmers, these characteristics are relevant to explain the effectiveness of a soil amendment. Therefore, I'm going to ask farmers if they are familiar with these two characteristics and check whether they use them to take adoption decisions. As P8 said, there is also a connection between the

"characteristics of soil amendments" and its "market price". It would be interesting to ask if farmers correlate these two previous concepts.

- R- "Liming" AND "Soil analysis"
  - To develop the connection between having a soil analysis, using it to take fertilization-decisions, and how the price paid by the farmer influences the previous connection, I should ask: Do you have soil analysis? do you use it to take fertilization-decisions? what percentage of the soil analysis was paid by you? Note that this is not the right order to ask these questions, as farmers might believe that the correct answer would be: "yes, I do have a soil analysis", "Yes, I use it to take fertilization-related decisions". Therefore, I should ask first "do you apply soil amendments?", "what type of soil amendments"; "why that specific type of soil amendment and not a different one" "do you use the soil analysis to take such decisions?"
  - I didn't ask, though, what percentage of farmers who buy soil amendments use the soil analysis and P10's thoughts on whether those farmers had paid for such soil analysis.
- R- "Soil Amendment type" AND "Price-Market"
  - I should ask farmers if once they have taken the decision to adopt a soil amendment, the price influences the type of amendment bought.

- Cacao varieties
  - R- "Grafting in the field-Malayo" AND "Speed up production"
    - I need to better understand what are the factors that explain that a farmer makes such decision to renovate solely the aerial part of the plant or the whole system. Is the objective to adopt the Malayo technique to speed up the production process? When do you do it, what are the conditions that might be present? I'm also missing the difference between grafting small plants at the nursery or in the field.

Document 6

October 22, 2021

Interview questions after data analysis from participants 7-10 before interviews with P11-13

Questions to extension agents

- Technical Assistance (TA)
  - How is TA provided in San Vicente?
    - Institutions?
      - Fedecacao: No of extension agents?
    - Projects?
      - How frequent? How many of those provide TA?
    - How is the interaction of the TA and the farmer?
      - Do you go to the farmer or does the farmer visit you?
      - Activities?
    - Frequency of TA

    - How often the interaction?
    - How long does it take?
    - Are farmers who are members of an organization more likely to receive TA?

Soil Amendments:

- Do you talk about soil amendments?
  - When do you recommend adopting soil amendments?
  - Do you know if the recommendations of using soil amendments are new?
    - When?
    - Do you know if Fedecafe recommends soil amendments?
  - How often do you recommend?
  - How is the recommendation process?
  - Which topics?
    - Soil pH? Bases relationship? Al? Heavy metals? Nutrient delivery?
  - Which percentage of farmers need soil amendments?
    - Why some of them do not need them?
  - How are the recommendations of using soil amendments provided?
  - Do they follow the recommendations you provide?
    - What percentage of those use it?
    - Why do you think some of them follow recommendations? And not others?
      - Trust in you?
      - Price of the recommendations? Do they adopt the cheapest ones?
  - Besides you, who else provide TA on soil amendments?
    - What about the providers?
- Have you seen if farmers feel a need for controlling pH?
  - Bases Relationship ? Control Al ? Nutriments delivery ?
- Do farmers believe that soil amendments are useful to increase production?
  - Do you believe that as well?
- Did you see a crop response of the soil amendment?
  - Where did you see that response, was it on the leaves, on the growth, or on the production, other?
  - Have you seen a different response when you apply soil amendments in areas of the farm with less shade?
  - Have you seen a different response when you apply soil amendments to clones compared to hybrids?
- Price paid by farmer.
  - Have you seen if the adoption of soil amendments is influenced by subsidies?
- Cocoa price?
  - How the price of cocoa influences the adoption of soil amendments?

  - Providers: who provided soil amendments?

Cacao varieties:

  - What percentage of San Vicente has clones?
  - What determines that cacao farmers adopt clones?
    - Age of the plantation?
    -
  - Do you talk about cacao varieties?
    - How often?
    - Which topics?
      - Do you talk about rootstocks?
      - What is the recommended rootstock?
      - What rootstock is used by farmers? Nurseries?
  - When do you recommend adopting clones?
    - When malayo?
    - When from seed?
    - Grafting in the field or in the nursery?
  - Source of the material? How many nurseries in San Vi?
    - Do you believe that cacao farmers trust you?
    - Do they follow the recommendations you provide?
- Do you talk about heavy metals? About Cd?
  - What do you say?
  - What are you recommending for Cd alleviation?
  - Do farmers feel a need to control Cd?
    - Does this need influences their adoption decisions?

Question to soil amendments providers

- What types of soil amendments do you sell?
  - Why not having a more diversified portfolio?
- For how long have you sold these soil amendments?
  - Experience-time on the market?
- Adoption Decision
  - What percentage of farmers use soil amendments?
    - Do they usually use more NPK or soil amendments?
  - Which is the soil amendment that farmers use the most?
  - Does a farmer usually buy the same one?
  - How often do farmers use soil amendments?
- Would it be possible to know the soil amendments market in San Vicente?
- Why farmers take the decision to buy soil amendments?
- Have you heard if they buy because they have adopted clones?
- What motivates farmers to buy soil amendments instead of NPK? Do farmers know their differences?
- Technical Assistance
  - Does a TA influence the decision to use soil amendments?
  - Does the TA recommend farmers to applying Soil Amendments?

        - o Is this a recommendation more common among coffee extensionists or among cacao ones?
    - How do you provide technical assistance (see code "Soil amendment provider" as a "source of knowledge" at the moment of selling the product, influencing the adoption of soil amendment (because they also sell other products such as fertilizers)?
- o How the farmers use the soil analysis to take the fertilization/related innovations?
    - How the farmers translate the soil analysis in the products bought?
- o Perceived need to control pH (bases relationships and Al) AND "knowing soil pH" AND "K- pH required for cacao"
    - Do farmers know the pH, bases, Al of your farm?
- o How the cocoa price influences the purchase of soil amendments? What percentage of buyers use the soil analysis to decide what to buy?
- o Price paid by farmer
    - Who pay for the soil amendment farmers use?
        - Projects, etc?
            - o What % is usually covered?
    - Do farmers adopt soil amendments because they were subsidized, or would they buy and use soil amendments if they would have to pay for the entire price?
    - How the price of the products influences the purchase decisions?
- o Do the providers know the reasons for the price differences?
- o What knowledge does the soil amendment provider have and where does she/he get it
- o Quantities of soil amendments sold.

Document 7
November 04, 2021
Interview questions after data analysis from participants 11-13 before interviews with P14-16

Questions to Farmers
General

- o "Working objectives"
- o "Livelihood strategies"
- o "Perceived Needs"
    - Ask based on the WO and Livelihood strategy.
    - Would you like to improve the status of your farm? What specific things (objectives)
        - How do you perceive the current performance of your farm is?
        - Are you ok with the current productivity you have?
        - What do you do to change the productivity?
- o "Technical Assistance (TA)"
    - Have you received TA?
    - Who provided it?
    - How many times did they reach out to you?

        - How was that interaction? Did they visit you?
    - "Access to projects"
        - Have you been beneficiary of a project?
        - Did the project provide you TA?
    - "Membership in an organization"
        - Are you a member of an organization of cocoa farmers?
        - Have you received any project through the organization? Which ones?
        - Have you received TA through the organization? How?
        - Do you follow their recommendations? When?

Soil amendments:

- "Perceived Response to Soil Amendments"
    - Have you ever applied soil amendments (explaining which types of soil amendments are out there)?
        - If NOT
            - Have you heard about soil amendments? Lime, silicates, gypsum.
            - Ask characteristics
                - Have you heard about the importance of using soil amendments? And Fertilizers? Have you heard about the nutrient cycle?
            - Ask Beliefs
                - Do you believe that soil amendments are useful to increase production?
    - When was the first time you apply it? How long ago?
    - Why did you take the decision to apply soil amendments at that time?
        - What motivated you to do so?
        - Did someone suggest you do so?
    - What did you apply? How much?
    - Did you see a crop response of the soil amendment?
        - Where did you see that response, was it on the leaves, on the growth, or on the production, other?
    - Do you have shade trees on the area you applied the soil amendment?
        - Have you seen a different response when you apply soil amendments in areas of the farm with less shade?
    - Did you apply the product to cacao clones or to hybrids?
        - Have you seen a different response when you apply soil amendments to clones compared to hybrids?
    - Do you know what are the characteristics of that soil?
- Adoption Decision
    - Do you apply soil amendments now?
    - Why are you still using soil amendments? Is someone encouraging you to do so?
    - IF NOT question

        - Why to adopt and not doing another activity, or to buy another product with that money (This applies to whatever practice/product they affirm they use)
    - When was the last time you applied soil amendments? How many times in the last year?
    - How much do you apply?
    - How often
    - What type of soil amendments?
        - Why that specific type of soil amendment and not a different one"
    - Does the price of cocoa influence your decisions to apply soil amendments?
        - Does the cocoa price influence the type of product you buy and/or the dosage you typically use?
- Technical Assistance
    - Did you talk about soil amendments with the TA?
    - Did the TA recommend you applying Soil Amendments?
    - Did the TA influence the decisions you took on adoption soil amendments? Do you follow the recommendations to use soil amendments? Why?
    - Did the TA indicated that you have a need to control pH?
- Perceived need to control pH (bases relationships and Al) AND “knowing soil pH” AND “K- pH required for cacao”
    - Do you know the pH, bases, Al of your farm?
    - Do you believe that those values should be modified in your farm?
        - Do you adopt/not adopt soil amendments because you believe/do not believe that?
    - Do you know what are the values recommended for cacao?
- Perceive need to control Cd
    - Do you know the Cd values of cacao of San Vicente/your farm?
    - Do you believe those values should be modified?
- Knowing innovations’ role in the crop system
    - Do you know what are the objectives of practicing these innovations? how did you know that?
        - Do you know how/if soil amendments control?
            - Soil pH
            - Heavy metals
            - Bases relationships (extremely important)
            - Al availability
            - Nutrient’s delivery
- Price paid by farmer
    - Who pay for the soil amendment you applied?
    - Have you received these innovations for free?
        - If so, was it through a project? (R- “price paid” AND “access to projects”)

- In the cases when a project/donor gives you the product: do you apply it in the area of the farm influenced by the project/donor, or you use the inputs in the whole farm/crop.
  - Do you do the same when you are the one who buys these inputs?
- Do you adopt soil amendments because they were subsidized, or would you buy and use soil amendments if you would have to pay for the entire price?

- Knowing Innovations' characteristics
  - Do you know what are the components of the soil amendment you use?
  - Are you familiar with the mesh size, and the purity of the soil amendment?
  - Do you know if the price of the soil amendment depends on this characteristic?
  - Do you know how the soil amendments affect the cacao crop?
    - How do you know that? Do you know it because of the perceived response to soil amendments?
- Believing soil amendments on productivity
  - Do you believe that using soil amendments increase the productivity of cacao (OR whatever other Livelihood strategy the farmer has)?
  - Do you believe that using NPK increase the productivity of cacao (OR whatever other Livelihood strategy the farmer has)?
  - Are your previous beliefs influenced by the price of the soil amendment and the NPK fertilizer?
  - Do you believe that the price of the fertilizers/soil amendments influences the crop response? In other words, the higher the cost of the product, the higher the response of the crop?
  - Are your previous beliefs that believe that using soil amendments increase the productivity of cacao influences by your Perceived Response to Soil Amendments?
  - "Recommendations from Fedecafe"
    - When did you start working with cacao?
    - Have you had coffee?
    - Were your previous generation working with other crops? coffee?
    - Have you been received training from the National Coffee Federation?
    - Did you apply soil amendments to the coffee?
    - Have you applied soil amendments to other crops you have had?
- Price-Market
  - How the price of the soil amendment influences the purchase decision? In other words, if you have decided to adopt a soil amendment, do you buy the cheapest one?
- Soil Analysis
  - Do you use the soil analysis to take fertilization (using soil amendments) decisions?
  - Do you have soil analysis of the cacao lot?
  - Who paid for the soil analysis you have?
- Subsidy Expectancy

        - Are you waiting for an upcoming subsidy to adopt soil amendments?
- Beliefs of using soil amendments on cocoa productivity

Cacao Varieties

- Percentage of farm with clones?
- How did you get those clones? the material, the workforce?
- when was the first time you heard about cacao clones? who told you that?
- What do you think about cacao clones?
- Do you believe that cacao clones are important to increase production?
- Why do you believe that?
- Who told you that?
- Have you seen that?
- Are you thinking about replace the hybrids you have for clones? Why?
- Price paid by farmer
    - Who pay for the cacao varieties (seedlings, seeds, scions, etc.) you have?
    - Have you received these innovations for free?
        - If so, was it through a project? (R- "price paid" AND "access to projects")
- Subsidy Expectancy
    - Are you waiting for an upcoming subsidy to adopt cacao varieties (renovation)?
- Technical Assistance
    - Did you talk about cacao varieties with the TA?
    - Did the TA recommend you applying cacao varieties?
    - Did the TA influence the decisions you took on adoption cacao varieties?

Questions to Soil amendments experts

- How does the TA influence the adoption of soil amendments?
- What does motivate farmers to use soil amendments?
    - How are cacao farmers different to other farmers?
- What determines the crop response to soil amendments?
- How has the soil amendment market evolved?
- Terminology of soil amendments
- What would be an ideal way to measure the adoption of soil amendment applications?
    - Applications in the last two years?
    - Yes/No
    - Dosage?
- What is the recommended
    - Frequency (what determines this frequency?)
    - Mesh size
    - Dosage
    - Form of application
    - Material?
- What determines the previous recommendations?
- Soil amendment characteristic

        - Does the mesh size apply only for carbonates? Or is it also a measured relevant for silicates and sulfates?

Document 8
November 08, 2021
Interview questions after data analysis from participants 14-16, after elaboration of Diagrams 4, and before interviews with P18-20.

Questions to farmers
Cacao varieties

- Area with cacao? With others?
- Percentage of farm with clones?
    - Were those clones subsidized?
        - How? A project? Fedecacao?
        - The plants/scion woods, the grafter?
        - Do you still have those clones? Did you change them?
        - What percentage of the area was affected by the projects?
- What do you think about cacao clones?
- What about hybrids?
    - Do you believe that cacao clones are important to increase production?
        - Why do you believe that?
- Have you worked with clones before?
- Have you seen clones in other farms? When?
    - Were those clones productive?
    - What do you think about the performance of those clones?
    - How that performance shaped your beliefs about clones?
- “Beliefs about clones”
    - Who talked to you about clones? A neighbor?
        - How the TA influenced such beliefs?
    - Do you believe that hybrids are important to increase production?
    - Do you believe that hybrids are important to increase quality?
    - Are you thinking about replace the hybrids you have for clones? Why?
        - Does the cost influence your decision of not doing it now?
            - Workforce?
    - If you would have to establish a new plantation, would you use clones?
    - Would you replace your hybrids for clones if a project would give you the plants? The workforce?
- Cadmium
- Do you see your farm as a business?
- Do you have other businesses?
- Do you live in the farm?
- TA

    - Are you aware of the "cuota de foment"?
- Seeing cacao as a business
    - Do you manage accounting records?
    - Do you consider yourself as a business mindset?
    - The objective of increasing productivity? Or increasing profits?
        - Perceived crop performance
            - Comfort zone?
    - Do you seek increasing production? How?

Soil Amendments

- Have you ever applied soil amendments (explaining which types of soil amendments are out there)?
    - If NOT
        - Have you heard about soil amendments? Lime, silicates, gypsum.
        - Ask characteristics
            - Have you heard about the importance of using soil amendments? And Fertilizers? Have you heard about the nutrient cycle?
    - Why did you take the decision to apply soil amendments at that time?
        - What motivated you to do so?
        - Did someone suggest you to do so?
- Do you have soil analysis?
    - How did you get it?
- When was the last time you applied soil amendments? How many times in the last year?
    - How much do you apply?
    - How often
    - What type of soil amendments?
    - Why that specific type of soil amendment and not a different one"
- Do you believe that soil amendments are useful to increase production?
- Technical Assistance
    - Did you talk about soil amendments with the TA?
    - Did the TA recommend you applying Soil Amendments?
    - Did the TA influence the decisions you took on adoption soil amendments? Do you follow the recommendations to use soil amendments? Why?
        - Did the TA indicated that you have a need to control pH?
- Perceived need to control pH (bases relationships and Al) AND "knowing soil pH" AND "K- pH required for cacao"
    - Do you know the pH, bases, Al of your farm?
    - Do you believe that those values should be modified in your farm?
        - Do you adopt/not adopt soil amendments because you believe/do not believe that?
    - Do you know what are the values recommended for cacao?
- Price paid by farmer
    - Who pay for the soil amendment you applied?

- Have you received these innovations for free?
  - If so, was it through a project? (R- “price paid” AND “access to projects”)
  - In the cases when a project/donor gives you the product: do you apply it in the farm influenced by the project/donor, or you use the inputs in the whole farm/crop.
  - Do you do the same when you are the one who buys these inputs?
- Do you adopt soil amendments because they were subsidized, or would you buy and use soil amendments if you would have to pay for the entire price?

Document 9

December 02, 2021

Interview questionnaire used for the telephone interviews with participant 1. These questions were asked in the same conversation in which the member checking took place.

- Who are the farmers who are buying plants?
  - Are they renovating?
  - Are they establishing from the beginning?
- Do people do nurseries in the farm? Why?
- Project?
  - How are projects providing subsidized resources (seeds, seedlings, grafters, etc.) to renovate/establish?
  - Do projects usually buy planting material from you?
- Types of rootstocks used. Why?
- How many people bring their own seeds to you?
- How many people buy grafted plants? Why?
- Types of clones used. Why?
  - What are farmers looking for?

APPENDIX E: POSITIONALITY STATEMENT

Interpretive Biography

During my childhood and adolescence, wonderful lived experiences in the rural area motivated me to select agronomist engineer as my bachelor's degree. In agricultural settings, it is common for agronomists (my profession) to develop their careers around limited crops instead of being experts in several farming systems. That has been my case. Currently, I am specifically interested in the cacao sector, where I have been working for the past nine years - my entire career. My background over cacao trees, the ones used as the source of chocolate, is framed in my country of origin, Colombia.

The rural area in Colombia is entirely heterogeneous, not only because of its complex geography but also the social diversity and social interactions. Due to diverse environmental conditions, the potential for agriculture in my country is immense; however, the agricultural sector, including the cacao sector, is not at its best moment. For instance, it has been reported that although Colombia can produce 1,500 kilograms/hectare/year of cocoa, the actual productivity is close to 400 kilograms. The work I've undertaken in the cacao sector has focused on solving some of its current problems. I've done that through different assumptions and utilizing diverse approaches. Before graduating from my BS, I did an internship for a chocolate company that became my employer. My work at this company was conducting research to tackle the cacao sector's main challenges. By that time, the natural sciences approach was the one I used; farms, laboratories, technological equipment, and experiments were among the means used to generate helpful information for cacao farmers. My knowledge about the natural components of the cacao sector system increased. But perhaps one of the most shocking things I learned was that essential issues impacting the cocoa crops already had feasible solutions. In other words, I realized that in many cases, cacao researchers didn't need to re-invent the wheel.

While working in the natural sciences, I missed the social component of the Colombian cacao sector. I pursued my Master of Science degree in a social science discipline: Agricultural and Extension Education, to remediate this. Extension education is an intentional effort to fulfill the essential needs of communities and people. However, one activity or event is not enough to accomplish this mission, which is why sustained programs are required. My primary research consisted of evaluating cacao programs based on the principle that program evaluation is a tool for making program recommendations. Now I recognize that the cacao sector goes along a natural and a social context. Then, I believe that finding solutions to its challenges must consider both worlds.

My current concern

It was December 2014, and I still remember that promising meeting I was participating in like it was yesterday. Farmers' cooperatives, research institutes, the industry, and the government were present there. Perhaps I still remember the date vividly because it was my first important reunion as a new employee of the chocolate company. Or maybe I still remind it due to the magnitude of the issue we discussed that day. The main character of that meeting was a contaminant present in the soils where cacao trees grow. That specific chemical element, cadmium, which I hadn't heard about before, had been recently regulated by international authorities. The lack of knowledge about feasible solutions to tackle this issue motivated this important meeting. From that day, combating the cadmium issue became a professional goal for me.

The interpretive framework used in this research

Pragmatism is the belief system that guides this dissertation research. Pragmatism claims that the truth (ontology) may be interpreted in terms of the practical effects of what is believed (Savin-Baden & Howell-Major, 2013). In other words, reality is what is useful, what is practical, and what works (J.W Creswell, 2012). As a result, pragmatists can view reality as a singular and independent from the research (e.g., when using a theory to explain a phenomenon) or can also consider multiple realities (e.g., when the researcher collects data on the experiences of participants regarding such phenomenon) (J. W Creswell & Clark, 2017). Pragmatists think that knowledge can be gained through various methods, which means that the research process might involve both quantitative and qualitative approaches to data collection (J.W Creswell, 2012; Savin-Baden & Howell-Major, 2013).

Even though this research is qualitative, it was initially planned to be a mixed-methods study. Indeed, the quantitative phase to test whether the qualitative results of this research generalize is being conducted when writing this dissertation. Therefore, I do not believe that one of these methods (qualitative-quantitative) is superior to the other. Depending on the research question, one method might be better suited to answer the query. In other words, I do believe, like others (i.e., Teddlie & Tashakkori, 2010), in the importance of the research problem/question for driving the methodological decisions in a study. Therefore, I consider that the research question plays a crucial role in the ongoing debate about what constitutes quality in research.

APPENDIX F: NOTES TAKEN DURING DATA VALIDATION

This document presents the notes taken during the second-round interviews conducted with five participants (P08, P05, P01, P19, and P06). The notes reflect the comments that interviewed participants had regarding specific concepts and concepts' relationships.

Member checking 1: Participant 08
Date: 11/16/2021
Results discussed: The adoption of soil amendments
Recording: unavailable

The researcher had a Zoom meeting with P08 to discuss the main findings related to the factors explaining the adoption of soil amendments. The use of the Zoom platform allowed the researcher to share his screen. The researcher presented an earlier version of the diagram depicting the concepts involved in the adoption of soil amendments. Overall, P08 indicated that the diagram was concise and complete. P08 only mentioned being surprised by not seeing a factor showing farmers' awareness of the importance of knowing aluminum on soils. Other notes are presented below.

- **Effect of "Access to capital" on "soil amendment adoption":**
  The researcher told P08 that he didn't find that the "access to capital" influenced the adoption of soil amendments as much as it affected the adoption of NPK fertilizers. P08 indicated that this "*is not a general fact, but often, due to the soil amendments price, farmers do not have access to capital as a critical resource*."
  The researcher mentioned that he heard from a participant (P16) that in some cases, due to NPK fertilizers' price, farmers replace NPK fertilizers' applications with soil amendments. To this previous affirmation, P08 indicated that "*Often, in some sectors, it occurs that farmers replace NPK applications with soil amendments, in particular with complex amendments [which are more reactive and promote higher crop's responses]*."
- **"Crop response to soil amendments"**
  Even before the researcher described the effect of the "perceived crop response to soil amendments," P08 affirmed that the previous was a relevant factor. P08 indicated that this factor is relevant as, based on his beliefs, farmers-in particular small farmers, are highly visual.
- **"Perceive need to control aluminum (Al)"**
  As mentioned earlier, P08 was surprised because he didn't see the "perceived need to control Al" as a relevant factor motivating the adoption of soil amendments. P08's surprise is explained because, during his professional experience as an extension agent, there has been a focus on teaching the farmer about the goal of tackling Al rather than controlling the soil pH. The researcher revised all the interviews based on this comment and found only four participants talked about aluminum. P08 (this participant) and P16 (manager of a soil amendment company) were two. The third participant was a cacao extensionist who manages a cacao farm (P05). Only one participant who talked about aluminum was a farmer (P06).

- **"Personality traits: managerial style[31]"**
  According to P08, "*it is common that the small farm holder doesn't have clear accounting records (kg/ha, equilibrium point). The farmer is visual; the tree is either green or yellow; it is ok, or leafless* [paloteado in Spanish]. *Their perception is visual."* P08 also indicated that the business-minded farmer usually has personal technical assistance who is the one who takes decisions, even if the owner (the businessman) doesn't know about soil related-topics.

Member checking 2: Participant 05
Date: 11/29/2021
Results discussed: The adoption of clonal cultivars and soil amendments
Recording: available

The researcher had a Zoom meeting with P05 to discuss the main findings of the research. The researcher shared his screen and presented the two diagrams describing the concepts involved in the adoption of clonal cultivars and soil amendments. Overall, P5 indicated that the concepts and the relationships of the concepts illustrated in the diagrams "*make a lot of sense as they encapsulate what one hears and see on the cacao regions.*" P5 also indicated that if one talks to cacao farmers about these topics, the responses would be related to the concepts identified on the conceptual frameworks.

The conversation started with a discussion around the presentation of the diagram **explaining the adoption of clonal cultivars**. Some notes from P5:

- **"Seeing clones characteristics" and "beliefs about clones"**
  P05 highlighted the importance of visual experiences to influence farmers' beliefs. P05 reaffirmed that farmers don't only look at the trees to see the number of pods. They also look at the cushions on trees as an indicator of the production of pods of that tree. In this case, a smooth surface of the trunk, especially around the cushions, indicates a deficient production of pods. By seeing this, farmers' beliefs about the productivity of certain clones are also shaped.
- **"Believes about clones:" myths**
  P05 also commented that farmers are constantly asking others about the characteristics of clones. This information shapes their beliefs. In some cases, there are myths about clonal cultivars with outstanding production. P05 indicated that on one occasion, a group of farmers asked him about a cacao cultivar with pods containing 100 beans and that produced 1 kg of cocoa beans with 4-5 pods when a pod of a common clonal cultivar has on average 35 seeds (Perea et al., 2013).
- **"Age of farmer" as a moderator of the relationship between "Adopting clones" and "Beliefs about clones"**
  The age of a farmer could also play a role in the relationship between "adopting clones" and "beliefs about clones" in the same way the "access to capital" does. P05 shares his

[31] This concept was previously named "seeing cacao as a business." During the interview with P08, the concept discussed was the latter.

own experience when deciding to renovate his family farm. Ten years ago, he told his siblings that if the renovation decision (going from hybrids to clones) was not taken by then, he would be older (60 years old) and would not take such a decision at that age.

- **"Increasing value of the farm" and "Adopting clones"**
  P05 also mentioned that another factor that could explain the adoption of clones is land valorization. A farm with clonal cultivar could be sold at a higher price than a farm with hybrids.
- **"Beliefs about clones"**
  When the researcher commented to P05 that most of the interviewed participants had beliefs that clones are helpful to increase productivity, P05 confirmed that this occurs because cacao farmers have been hearing about clonal cultivars since a long time ago.
- **"Beliefs about hybrids" and "seeing hybrids characteristics"**
  P05 affirmed that some hybrids produce lots of pods (100). However, he asserted that this production is not stable across all the hybrid trees. He also affirmed that if one compares the production of an outstanding hybrid tree with a good clonal cultivar tree, the production of the hybrid could be higher than for the clonal one. However, as mentioned earlier by P05, the number of hybrids producing more than 100 pods is low.
- **"Decision to renovate plantation or to establish a new one"**
  The previous is an economic decision. Farmers, according to P05, leave plantations with hybrids and establish new areas with cocoa instead of renovating the old hybrids plantations because the latter might still have some cocoa production.
- **"Context: history of clonal cultivars in San Vicente" and "subsidized innovation"**
  P05 briefly describe the history of the introduction of clonal cultivars in San Vicente, his hometown. According to him, a couple of extensionists from Fedecacao introduced this propagation technique in the municipality in 1993-1994. At that time, clonal cultivars were not well known because the propagation method was through seeds (hybrids). As these extensionists didn't have access to the scion wood, they started to look for productive cultivars within the producers' farms. When the first nursery with clonal cultivar was established, Fedecacao had to give the plants free. Around 100-200 plants were given to innovator farmers with the idea that these farmers would experiment and see the differences between clones and hybrids. P05 finalized the story mentioning that before clonal cultivars, establishing a plantation with hybrids was easier; therefore, the initial adoption of clonal cultivars was promoted by subsidizing the planting material.

Discussion about the adoption of **soil amendments:**

- **Context "terminology"**
  P05 affirmed that the word soil amendment is something new. Usually, farmers and extensionists talk about lime.
- **"Beliefs of using soil amendments" and "perceived crop response to soil amendments"**

P05 confirmed that the perceived crop response to soil amendment applications explains farmers' beliefs towards using soil amendments. However, the "perceived response," particularly in San Vicente, is affected by this municipality's high variability of soils. By providing the example of his father-in-law, P05 indicated how, because of a mistake, the soil analysis taken on his farm didn't consider the different types of soils of the farm. Under those circumstances, the recommendations of applying lime didn't correspond to the actual requirements of that specific lot in which lime was applied.

- **"Perceived need to control Al"**
  According to P05, the recommendations for using soil amendments were directed towards increasing soil pH rather than controlling aluminum. As reported by P05, the message regarding the importance of maintaining aluminum in soils has been recently communicated. Indeed, P05 affirmed that as a cacao extensionist, he started to talk about the control of aluminum by applying soil amendments around five years ago.
- **Context "history of soil amendment recommendations in coffee"**
  P05 confirmed that the application of soil amendments was not part of the recommendations given by coffee extensionists from the National Coffee Federation (Fedecafe) in San Vicente in the past. When P05 started to study for his bachelor's degree, most of the soil analyses were conducted through Fedecafe. However, even though coffee farmers had soil analysis, there were no recommendations for using soil amendments.

Member checking 3: Participant 01
Date: 12/02/2021
Results discussed: The adoption of clonal cultivars and soil amendments
Recording: available

The researcher had a telephone (WhatsApp) meeting with P01 to discuss the main findings related to the factors explaining the adoption of cacao clonal cultivars and soil amendments. The conversation began with the presentation of the diagram explaining the adoption of clonal cultivars. Some notes from P01:

- **"Adoption of clones" and "Subsidized innovation"**
  After the researcher presented this connection, P01 indicated that the adoption of clones due to subsides "*is the most common here in San Vicente and Colombia."* P01 also mentioned that many farmers currently pay for the innovations. Nonetheless, he affirmed that the previous connection is also valid.
- **"Adoption of clones" and "Beliefs of clones on productivities" and "beliefs of clones on facilitating labor"**
  P01 also suggested that not all hybrids are unproductive, a comment that other participants also made. However, P01 believes that farmers who adopt clones evidence their benefits, such as the case of increased efficiency on labor, and lower pod indexes (number of pods needed to get one kg of dry cocoa), compared to hybrids.

P01 recognized that "seeing" is an essential factor in shaping farmers' beliefs. For him, *"In our world, we are used to seeing to believe."* Nonetheless, P01 also recognized that besides seeing the clones' characteristics, farmers' experiences in their farm is also critical in shaping their beliefs about clones.

Regarding the beliefs that some farmers pose that hybrids are better than clonal cacao, P01 mentioned that 4-6 decades ago, the **"forest rent"** influenced the positive performance of hybrids.

- **“Adoption of hybrids” and “beliefs”**
  This discussion was beneficial to clarify the operational definition that will be used regarding the adoption of clonal cultivars. P01 mentioned that some farmers propagate their hybrids by sowing the seeds. As the cacao seeds result from a sexual combination in which the male flower pollinates the female flower, there is no guarantee that the plant's phenotype will be conserved in their offspring. P01 mentioned that farmers should know this principle and use grafting techniques to propagate outstanding hybrids from their farms. Under those circumstances, the concept of clonal cultivars used in this research will consider the hybrid plants propagated via grafting. i.e., the 100 plants that P19 propagated from her hybrids are considered in this research as clonal cultivars, as P19 multiplicated them using grafting techniques.
- **Moderation of “access to capital” of the R- “adoption” and “beliefs”**
  Once the researcher described the previous connection, P01 indicated, “*yes, Alejandro, that* [the relationship] *is that way*.” P01 also emphasized that when farmers’ livelihoods are supported on hybrid trees, the change of those hybrids for clones is not influenced by the farmers’ beliefs.
- **“Seeing cacao as a business”**
  P01 mentioned that, in his opinion, this concept is not very relevant to explain the adoption of clonal cultivars as there could be situations in which farmers might see cacao as a business and adopt hybrids. The case of P17 reflects this situation. What P01 described as a personal trait influencing the adoption of clones is being “risk-takers.” P01 described himself as an innovator.
- **“Knowing Cd solutions”**
  P01 affirmed that there are no current solutions to Cd
- **Context of “decision to use seedlings from nurseries; preferences for grafting on farm”**
  P01 provided a detailed explanation of why farmers in San Vicente prefer to buy rootstocks from nurseries. His explanation is congruent to what this research found.

Discussion about the adoption of **soil amendments:**

- **“Adoption of soil amendments” and “TA”**
  P01 affirmed that the extension agent influences the adoption decision. P01 mentioned that in San Vicente, farmers are skeptical, which is not the same in regions with no cacao culture.

- **"Adoption" and "perceived need to control pH"**
  P01 agreed that this relationship is important. He also affirmed that the focus is on controlling pH, not aluminum.
- **"Cd"**
  Farmers, according to P01, are scared about Cd. However, there is a lack of knowledge on how to control it.
- **"Access to capital" moderation Rs- with "adoption of soil amendments"**
  Farmers adopt soil amendment because it is cheaper than NPK fertilizer, as P01 confirmed.
- **"Personality trait: Innovativeness" and "adoption of soil amendments"**
  P01 indicated that being an innovator is not as relevant to adopting soil amendments as the perceived need to use this innovation motivates such behavior.

Member checking 4: Participant 19
Date: 01/22/2022
Results discussed: The adoption of clonal cultivars and soil amendments
Recording: available

The researcher had a telephone meeting with P19 to discuss the main findings of the factors influencing the adoption of cacao clonal cultivars and soil amendments.

The conversation began with the diagram explaining the adoption of **clonal cultivars**. When asked about the overall results found by the researcher, P19 affirmed that "*the story is adequate because that is the truth."* Some of the comments from P19 are described next.

- **"Adoption of clonal cultivars" and "Subsidized innovation"**
  P19 supported the previous connection, indicating that farmers do not adopt agricultural innovations in some cases due to the lack of resources. As P19 said, *"sometimes one doesn't do the practices due to workforce constraints. In other cases, if you have the personnel, you don't have the seedlings*."
- **"Seeing clonal cultivars characteristics" and "beliefs of using clones"**
  P19 mentioned that "seeing clonal cultivars characteristics" is critical to change the "beliefs of using clonal cultivars," which led to improvements on the farm.
- **"Beliefs of using cacao clones on facilitating labor"**
  When asked about the benefits of clones, P19 affirmed that clonal cultivars facilitate labor.
- **"Beliefs of using hybrids"**
  P19 also recognized the importance of having hybrids to "*conserve the tradition*" because some hybrids have outstanding performance.
- **"Perceived performance of clones" and "Beliefs of using cacao clones"**
  P19 mentioned that when "*one looks at the clones and one realize that they are more profitable. One starts to change the way one thinks* [about clones]*."*
- **"Adoption of clonal cultivars" and "personality traits"**

P19 agreed that personality traits are essential to understanding farmers' behaviors.
Discussion about the adoption of **soil amendments:**

- **"Beliefs of using soil amendments on cocoa productivity"**
  As described in the conceptual framework, P19 affirmed that the objective of using soil amendments is to increase cocoa productivity and improve soil conditions. When asked about the consequences of enhancing the soil, P19 indicated that the primary goal of improving soil conditions is to increase production.
- **"Adoption of soil amendments" and "perceived need to control pH"**
  P19 confirmed the connection between "knowing soil pH," "knowing plants as soil indicators," and a "perceived need to control pH."
- **"Perceived need to control aluminum"**
  P19 indicated that farmers are usually concerned about controlling pH, nitrogen, phosphorus, potassium, sulfur, but not aluminum.
- **"Perceived need to control cadmium (Cd)"**
  P19 reaffirmed that, like the case of aluminum, cacao farmers do not perceive a need to control cadmium. In this way, there is a lack of knowledge regarding the potential solutions to this problem.

Member checking 5: Participant 06
Date: 01/22/2022
Results discussed: The adoption of clonal cultivars and soil amendments
Recording: available

The researcher had a telephone meeting with P06 to discuss the main findings of the factors influencing the adoption of cacao clonal cultivars and soil amendments.
The conversation began with the diagram explaining the adoption of **clonal cultivars**. Some of the comments from P06 are described next.

- **"Adoption of clonal cultivars" and "Subsidized innovation"**
  P06 affirmed that many farmers in San Vicente have clonal cultivars due to donations. P06 also talked about producers' organizations' role in promoting such incentives.
- **"Adoption of clonal cultivars" and "Technical Assistance (TA)"**
  When the researcher talked about the role of TA in influencing "beliefs of using clones," P06 mentioned that one of the consequences of the TA and research on clonal cultivars in San Vicente is the loss of genetic diversity in cacao.
- **"Beliefs of using clones on cacao genetic conservation"**
  The previous comment on TA reaffirmed the findings that some farmers who still adopt hybrids do so to conserve the genetic resources of cacao.
- **"Beliefs of using cacao clones on productivity"**
  P06 mentioned that some hybrid plants could produce 100-200 pods, compared to clones that produce around 30 pods. This response has been consistent with other participants who recognize that elevated production of pods is a characteristic of hybrid plants. However, the number of pods doesn't necessarily reflect the "productivity" trait of a cocoa variety, as the number of beans per pod and the beans' weight also influence the

actual production (kg) of cocoa beans produced on a farm. Also, as some participants affirmed, the cocoa production of hybrid plants is less stable than clonal cultivars. In other words, in a cocoa farm composed of hybrid trees, some plants produce a high number of pods while there is a remaining percentage of plants that do not produce at all. When P06 was asked about productivity as a whole (kg instead of the number of pods), he affirmed that with hybrids, "…*in one hectare of cacao there could be 700 plants that were productive and 300 that were not, but with clones, all of them are productive, that's the truth.*"

- **"Personality Traits: conscientiousness"**

The consolidation of "conscientiousness" as a relevant factor for adopting cacao clones and soil amendment occurred after the previous member checking (P01). Regarding the influence of this personality trait on the adoption of clonal cultivars, P06 affirmed that *"they are conformists [some farmers]. They do not think that clonal cultivars could enhance the harvest. If they produce 500 kg, they could be producing [with clonal cultivars] 800-1000 kg. So, they are there with what they have."*

- **"Perceived need to control cadmium (Cd)" and "knowledge on clonal cultivars on Cd alleviation"**

P06 affirmed that information about Cd is still undisclosed. Even though he had the opportunity to visit a research station where there was ongoing research trying to reduce Cd uptake by using different cacao varieties, P06 indicated that "*people don't that*."

- **General thoughts about the conceptual framework**

After explaining the conceptual framework explaining the adoption of clonal cultivars, P06 indicated that the phenomenon *"was summarized adequately."*

Discussion about the adoption of **soil amendments:**

- **"Having soil analysis" and "Knowledge on visual deficiencies and indicator plants" on "knowing soil pH" and "Perceived need to control soil pH"**

P06 affirmed that soil analysis is crucial to the adoption of soil amendments. The soil analysis and the recognition of the visual deficiencies on the plant are necessary to generate the perceived need to control pH and aluminum.

- **"Word of mouth" on "Perceived need to control pH"**

P06 recognized that there are farmers whose decisions are guided by external influences, particularly social pressure. P06 included the example of the farmer who applies soil amendments because their neighbor is doing so.

- **"Knowledge on soil amendments on pH control"**

P06 agreed that there is common knowledge that soil amendments are helpful to control soil acidity.

- **"Perceived need to control aluminum"**

P06 was aware that aluminum is a component of the soil that must be controlled through agricultural practices.

- **"Perceived need to control cadmium (Cd)" and "knowledge on soil amendments on Cd alleviation"**

P06 recognized that, so far, Cd hasn't been widely discussed because it could become a social concern. When asked about the potential solutions to this problem, P06 said he doesn't know about a feasible way to tackle this issue, even though he is aware of institutions researching this topic.

VITA
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Educational Experience

Master of Science: Agricultural and Extension Education - International Agriculture and Development (Dual title degree).

- The Pennsylvania State University-State College, PA, The United States of America (U.S)
- August 2017-August 2019
- Thesis title: Evaluating the success of a cacao program in Colombia: a case study of the Productive Partnership Project (PAAP).

Bachelor of Science: Agronomist Engineering

- Universidad Nacional de Colombia – Medellín, Colombia.
- January 2008- April 2014
- Thesis title: Etiologies and incidence of tree tomato (*Solanum betaceum* Cav.) crop diseases in Antioquia-Colombia

Language skills:

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Teaching Experience

Teaching Assistant -Universidad Nacional de Colombia

Courses:

- Agricultural Economics: June 2011 - June 2012
- Agricultural Business Administration: January 2012 - June 2012
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Teaching Assistant- The Pennsylvania State University

Courses:

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- AEE 520- Research Methods: Spring 2021

Publications:

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