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# The impact of agricultural credit on farm level technology adoption

- The case of cacao production in post-conflict Colombia

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# Abstract

The purpose of this master thesis is to investigate how access to credit in Colombia's cacao production affects technology adoption. Technology adoption is defined as management practices, considering that low crop quality and productivity are the main problems faced by cacao farmers in Colombia. The empirical part focuses on the case of the cacao growing in 121 farms in three different municipalities located in the Southern region of the department of Tolima, Colombia. Data were obtained through primary sources from a farmer survey. Cluster analysis is used to construct two groups of management practices. Cluster membership is then explained in a regression model that includes among other variables the use of credit. Contrary to the initial hypothesis, there is no evidence of a positive impact of agricultural credit on technology adoption. These results could be used for a better allocation of credit access linked to the improvement of management practices like pruning and fertilization already being practiced by one group of farmers (Cluster 2) who are not the main receptors of agricultural credit. This case could hopefully contribute to an overall more efficient allocation of credit for the cacao farming in Colombia.

# Abbreviations

| | |
|---|---|
| AGROSAVIA | Colombian Corporation for Agricultural Research |
| DANE | National Bureau of Statistics of Colombia |
| FAO | Food and Agriculture Organization of the United Nations |
| FEDECACAO | Colombian Federation of Cacao Growers |
| FINAGRO | Fund for the Financing of the Agricultural Sector of Colombia |
| GDP | Gross Domestic Product |
| SAC | Colombian Farmers Association |
| WFP | UN World Food Programme |

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# 1 Introduction

## 1.1 Aim and delimitations

Based on the assumption that a better understanding of the impact of credit over technology adoption can help to design more tailored financial instruments that help farmers to increase their adoption rate and hence, their productivity and the quality of the cacao beans they harvest (Obuobisa-Darko, 2015), this research investigates the following question:

What is the impact of agricultural credit over technology adoption of small–scale cacao producers in three different municipalities of the department of Tolima in Colombia?

The objective of this research is to understand the influence of credit access in technology adoption within cacao production in three different municipalities of the department of Tolima in Colombia. To reach this overall objective, it is necessary to:

First, define the most adequate indicators to measure technology adoption at the farm level based on a literature review. In a second stage, it is required to establish the most appropriate method to analyse how agricultural credit access can be explained by set management practices that can also be understood as technology adoption factors (Doss, 2006; Mwangi,and Kariuki, 2015). For this purpose, cluster analysis and logit regression analysis were used to fine-tune the data and narrow down the number of important variables to avoid possible multidimensionality problems common in the type of data sets like the one used for this work (UCLA, 2016). Those initial results will be used to explain better ways to design credit instruments in the policy recommendations component of this research.

In this context, it is important to emphasize that, when talking about technology adoption and management practices, within this research they will be used as a linked term, for the simple fact that technology adoptions in countries like Colombia are primarily based on the introduction of new procedures and not necessarily in the acquisition or rental for use of new machinery.

Even though the publication of studies in the area of technology adoption in agriculture has been significant (Sunding and Zilberman 1999, Parvan 2011, Taher 1996; Mwangi and Kariuki 2015; Place & Swallow, 2000; Lee, 2005) there is a lack of literature related to specific factors explaining low rates of adoption for the case of cacao production, particularly in Colombia. The gap is precisely the absence of information that the described academic literature possesses in terms of measuring management practices as an indicator of technology adoption. This research aims to contribute to filling this gap. For policy purposes regarding technology adoption and management practices, this document expects to contribute as an insight showing how these two elements are related to credit for the principal stakeholders involved in the cacao agribusiness, namely farmers, farmers associations, industry and public as well as private institutions, providing agricultural credit for this sector,

Another expected input of this master thesis is to contribute to the understanding of the main factor driving the adoption of technologies among the cacao farmers in three municipalities of the South American country here studied. This knowledge could thus lead to an adequate formulation of policy recommendations to be considered when designing and offering agricultural credit to this subsector of the agriculture business, especially among those farmers who decided to change their coca leaves plants for this product within the framework of the Crop Substitution Programme mentioned in the Context component of this document.

# 2 Background and context of cacao farming in Colombia

## 2.1 Background

The Colombian government signed a peace agreement with the guerrilla group known as the FARC in 2016, putting end to an armed conflict that lasted more than a half-century. This was the oldest conflict in place in the whole western hemisphere when it ended, leaving a total amount of more than 6 million victims and more than 262 000 deaths (Romero, 2020).

As the production of cocaine was directly linked to the armed conflict after the peace agreement, different strategic crops such as coffee and cacao were identified as a viable option for the Governmental Crop Substitution Program due to its economic characteristics and viability in the international markets (High Presidential Council for the Post-conflict, 2018). This thesis focuses exclusively on cacao, a strategic alternative crop, preferred by the Colombian Government as a suitable substitution option.

The agriculture sector represented 6.4% of the GDP in 2019. 70% of the composition of the Colombian agricultural GDP is based on 6 products: flowers, bananas, coffee, sugar, rice, and potatoes. Colombian farming sector grew around 2% in the last years (Ministry of Agriculture of Colombia, 2018), nevertheless, during the last two governments the budget cuts for the Ministry have been significant: in 2015 it fell to 54.5%. For 2020, the expenditure budget represents 20% less compared to the amount assigned during 2019 (SAC, Colombian Farmers Association, 2019).

When describing an overview of agriculture in Colombia, it should also be mentioned that the last agriculture census revealed that 44,7% of the population living in rural areas are below the poverty line (DANE, 2015). In recent years, crops like palm oil, mango, avocados, and cacao have gained notoriety due to a surge of the export of those commodities (Ministry of Agriculture of Colombia, 2018). Colombian agriculture lacks sustainable productivity and enough financial means to access technology adoption, namely more credits specifically designed to support farmers in the betterment of their management practices in a sustainable way, especially in the cacao sector (Ortiz et al., 2014).

## 2.2 Problem

The cacao supply chain worldwide is characterized by low prices at the farm level not matching production cost and/or living income for farmers (Fountain and Hürtz–Adams, 2018). In addition, farmers face credit and general liquidity constraints when growing this crop (Zeller, Diagnea, and Mataya, 1998). As a result, low productivity and low production quality are the two main problems faced by cacao farmers in Colombia (Acosta and Villarraga, 2006; Arias, 2016). From the environmental perspective, also important when describing the problematic situations faced by cacao farmers, it should be mentioned that large scale intensive cacao production, if not properly managed, can result in reductions in biodiversity and soil fertility, erosion, and stream sedimentation associated with the use of agrochemicals (Ntiamoah and Afrane, 2008).

According to the National Federation of Cacao Growers (FEDECACAO) and Ortiz et al. (2014), the main challenges faced by farmers are related to the low productivity of its hybrid trees having low levels of tolerance to pests and diseases, due partially to the fact that 80 000 out of the 147 000 ha. planted are too old; the low density of trees in production per hectare; the difficulties for cacao growers to implement the recommendations of integral management of the crop delivered through a (still) small amount of technical assistance available. Among these challenges are also phytosanitary problems that difficult access to markets and could be solved through better management practices and technology introduction in processes. Low efficiency in the potential hectares available for planting should be mentioned too when describing the challenges faced by this sector (MicroEnergy International, 2017). In the case of quality and productivity, an important barrier has been the absence of efficient technologies throughout the farm level stage. As defined by García–Cáceres et al.(2014, p.3).

> (…) the national production has been decreasing lately, mainly because of a) low grain local price, which leads the farmers to quit plantation improvement processes and simply assume a harvesting attitude; and b) the growing attack of the crop by pests and diseases, in turn, associated with poorly trained personnel in charge of technology transfer, finally resulting in the hindrance of necessary productive increases of the production process, namely irrigation, drying, and storage, adapted to the geoclimatic context of the different regions where this crop is planted.

As described in this quote, there is a void in the farmers' knowledge about the most suitable technologies to adopt and how these factors affect their competitiveness and income.

Other different researchers like Torres and Rodríguez (2015, p. 20) and Acosta and Villarraga (2006, p. 72) have also mentioned, as part of the current problematic situation, that there is little knowledge of the solutions in terms of technology use.

Continuing with the description of the problem as found in the literature it can also be said that cacao growers face the difficulty of financing their key activities such as land preparation, seeds and inputs purchase, storage, transportation, certification, technological equipment purchase, paperwork and intermediation for export or commercialization. The reasons explaining these obstacles besides the structural ones already mentioned are – according to García–Cáceres et al.(2014), Ortiz et al.(2014), and Acosta and Villarraga (2006) – a mixture of private and public deficiencies reflected as part of the problem in the financial market offer to provide farmers with credit alternatives when their cash flow is not enough to match their basic input needs. As found by the last agricultural census, only 11% of the total producers asked for credits in 2014 (DANE, 2015). This figure is alike to the one found by Acosta and Villarraga (2006, p. 45) in their study case in the municipality of El Dorado (Col.). These problems are a common element in the literature when describing the sector challenging situations, likewise is the improvement of a more profitable business model. The availability and use of more flexible financial services that can be adapted to the context of cacao farmers are also weak in the Colombian context. The mixture of these deficiencies results in a barrier when it comes to improving competitiveness through productivity and quality, which also considers the environmental and social challenges of the farmers' communities. A transversal component of these problems is then the lack of access to financing (MicroEnergy International, 2017).

The main figures about the cultivation and economic exploitation of *Theobroma cacao* in Colombia are the following: This South American nation is the 4th largest cacao producer in Latin America after Brazil, Ecuador, and the Dominican Republic. It is among the main 10 world's cacao producers (García–Cáceres et al., 2014, p.32). The country has more than 2 million hectares suitable for the development of cacao crops (García–Cáceres et al., 2014, p.33), but currently only 147 000 ha. are sown with this cacao tree. 37 000 families, out of which 90% are smallholders, have cacao trees in their farms (García–Cáceres et al., 2014, p.33). According to FEDECACAO (2017); , productivity is 512 kg/ha/year. The total production per year has moved between an average of 33 000 tons in the last decade (García–Cáceres et al.,2014, p.32) to the production of 66 000 tons in 2017 (FEDECACAO, 2017); out of these, 12 000 tons were sold in the international markets (FEDECACAO, 2017). To have a world market overview for means of comparison reference, Table 1 is useful:

*Table 1. World cacao production*

| Production of cacao beans in 2017 (thousand tons) | | |
|---|---|---|
| **Africa** | | 3625 –76.4% of the world´s production– |
| Côte d'Ivoire | 2020 | |
| Ghana | 970 | |
| Cameroon | 246 | |
| Nigeria | 245 | |
| Others | 145 | |
| **America** | | 739 –15.6% of the world´s production– |
| Brazil | 174 | |
| Ecuador | 270 | |
| Others | 295 | |
| **Asia & Oceania** | | 379 –8.0% of world´s production– |
| Indonesia | 290 | |
| Papua New Guinea | 40 | |
| Others | 49 | |
| World | 4744 | –100 % of world cacao production– |

*Source: ICCO, 2017.*

As shown in table 1, Colombia is not a major player in cacao world production. The African continent is the source of 76.4% of the world´s cacao production, while in the South American region Brazil and Ecuador are ahead of Colombia.

Before proceeding with the initial description of technology component of this research, this document needs to make clear that it is written with the awareness of the main economic, political, and practical problems concerning the technology adoption concept but they will not be discussed in depth here for the sake of the focus of this research. The global cacao market worldwide still faces serious and deep problems to be sustainable for its producers.

The social implications of this situation are mainly related to equity for cacao farmers who still suffer in a clear majority from poverty and not enough income to have decent living conditions. When the low prices are benefiting the big players of this commodity market and the growers do not have guarantees of an income level that surmounts the production costs, an unbalanced situation exists characterized by the absence of economic sustainability.

Cacao plays a very important role for small peasants as a cash crop because it provides income to buy food (Bentley et al., 2004 cited in Franzen and Borgerhof, 2007) and is especially important in areas where food security has been a problem (Belsky and Siebert, 2003 cited in Franzen and Borgerhof, 2007). This has been mainly seen in the vast majority of Colombian rural areas where, according to the 2015 National Nutrition Survey, 54 % of the population were food insecure and lacking access to basic nutritious food (WFP, 2017).

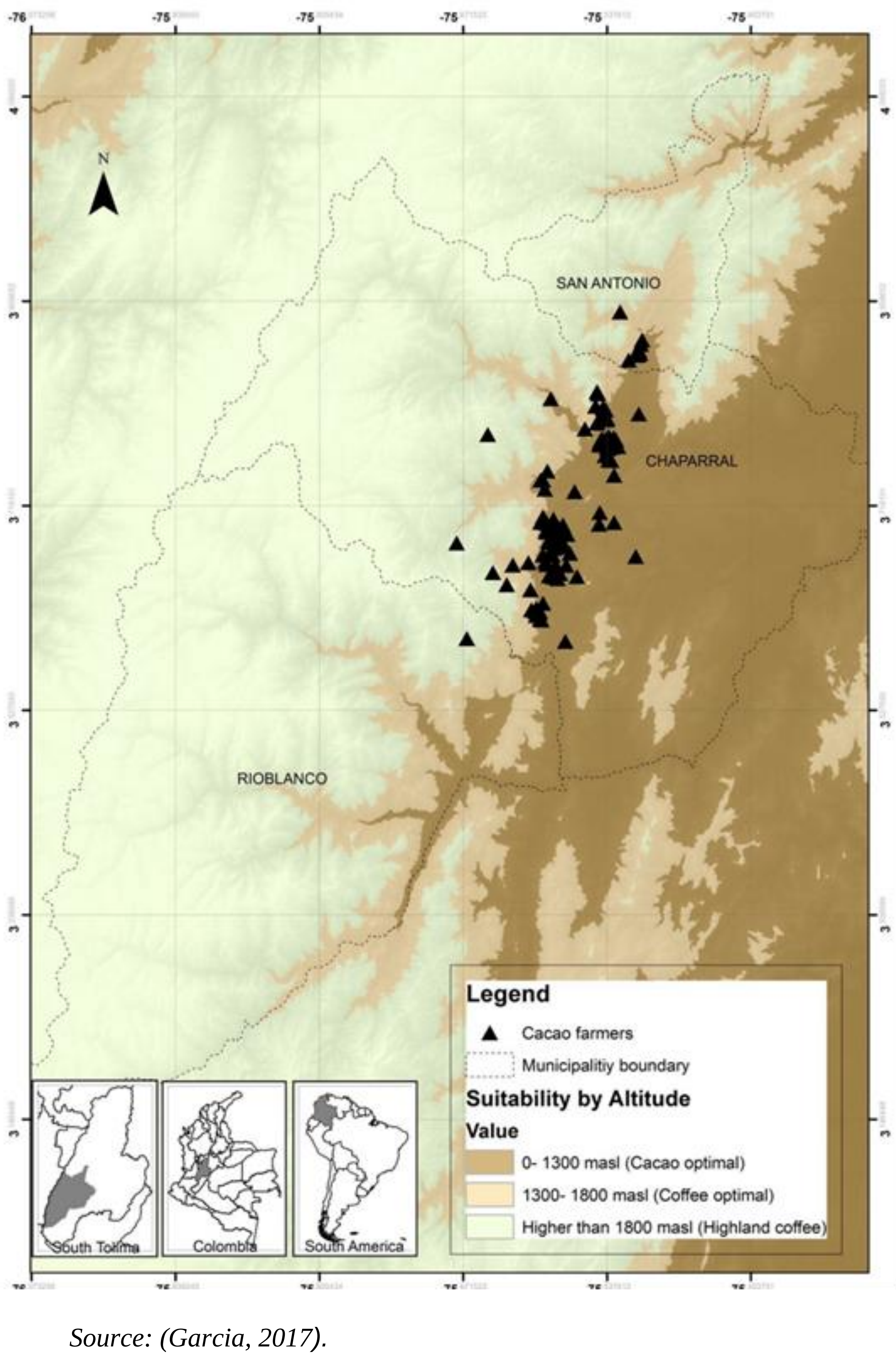
Bearing the late figures and the problems of credit and capital constrain for tech adoption in mind, a few more ideas about Colombian cacao production are important. For the Colombian case, besides the overall problems faced by the agricultural sector, efficiency in its production processes and credit availability are among the main difficulties cacao growers must cope with.

The adoption of technology and the betterment of management practices become crucial particularly for low and middle income countries (Lee, 2005), such as Colombia, holding vast uncultivated areas but using little or no technologies in their agricultural production (Bizikova et al., 2020). In this context, it is important to mention that, due to the need for feasible solutions, concepts like agricultural credit and their practical implication within production systems have permeated the academic debate, especially about the agri-food sector (Franzen & Borgerhoff Mulder, 2007).

The survey to obtain the data this work uses for the empirical component was carried out in the municipalities of Chaparral, Rioblanco and San Antonio, all of which belong to the region of South Tolima (Figure 1). Chaparral covers 2124 km2 (10% of the total area of the Department of Tolima) and is the most densely populated municipality of the region. Rioblanco covers an area of 1443 km2 (6.8% of the total area of Tolima) and San Antonio covers 389 km2 (1.8% of the total area of Tolima). The three municipalities are settled across the eastern side of the Andes mountain range (*see figure 1*).

More than three-quarters of the study area are highlands (higher than 1500 meters above sea level) which are more suitable for crop production and thus, agriculture is the main economic activity. The mean temperatures are 24.9ºC, 23.6ºC and 23ºC for Chaparral, Rioblanco and San Antonio respectively. Lowlands in the eastern part of the region are used mostly for animal husbandry and human settlements in these areas are not influenced by mountain agriculture in their production schemes. Cacao farms are found in the low mountain areas where the population has a strong influence on the coffee farmers' cooperative.

*Figure 1. Map of the studied region showing surveyed households' location*




*Source: (Garcia, 2017).*

# 3 Literature review

This sections contains a literature review about the two main topics discussed in this master thesis technology adoption and agricultural credit.

## 3.1 Technology adoption

As stated by Sunding and Zilberman (1999, p. 1): “Agriculture has also been significantly affected by institutional change. Innovations — new ways to perform tasks, new products, and new procedures — are the elements of technological and institutional change”. These authors also mention in their research that agriculture has made tremendous strides globally because of new agricultural technologies since the decade of 1960 (P.32). “A technology is simply the application of scientific knowledge for a certain end. A project or a technique can still be considered a technology even if the science is many steps removed from the eventual implementer (Parvan, 2011, par. 4)”. These two quotes illustrate how technology is not only the mechanization of production but also the improvement of agricultural practices.

Recent research in agricultural economics has an undeniable lack of information related to technology adoption for a commodity such as cacao. This is especially relevant when analyzing cases from global south countries like Colombia (Lee, 2005). Moreover, another of the gaps found in the available literature according to the conclusions from the comprehensive systematic literature review on this topic, conducted by Fu Jia et. al.(2018, pp. 18–19) is: “a lack of representation of the suppliers’ voices. Researchers usually conduct empirical studies from the buyer’s perspective, sometimes, therefore intentionally ignoring suppliers in developing countries due, in part, to the difficulties of accessing data”.

Sunding and Zilberman (1999), classified management practices as a type of agronomic innovation. These authors set this distinction while explaining that innovation in agriculture has different forms. As the variables used in this research account mostly for management practices, this way of understanding technology adoption is very important.

To explain the main elements of technology adoption in cacao production, the work of Taher (1996) is an important reference too. It concludes that main factors influencing smallholder technology adoption and application in cacao production are the following: A) the origin of farmers (dummy variable that takes on the value 1 if the farmer is migrant and 0 if indigenous), B) the number of neighbors known closely C) level of education, D) the number of family workforce and E) farm gross output and F) annual crop area exploited. Cacao production is insignificantly affected by fertilizer application and significantly affected by pesticide application. Taher also concludes that gross margins of actual farmer practices remain possibly to be increased by maximizing the use of the land available, introducing a more appropriate application of technology, and employing family labor optimally in both on-farm and off-farm activities (p.116–117).

When examining the elements influencing the adoption of new agricultural technology by smallholder farmers in developing countries, the research performed by Mwangi and Kariuki (2015) was considered too: they concluded that the perception of farmers towards new technology is a key precondition for adoption to occur. Other factors they also found relevant were A) human-specific factors, B) economic factors – such as credit – C) technological and institutional factors and D) farm size.

Parvan (2011, Phr. 17) also mentions that main factors presented in literature when measuring technology adoption, in general, are the following: A) farm size, B) risk exposure and capacity to bear risk, C) human capital, D) labor availability, E) credit constraints, F) tenure and G) access to commodity markets.

The same author presents the following 3 types of adoption that can be found on the farm and local levels: 1) individual vs. aggregate adoption, 2) singular vs. packets of technologies available for adoption, and 3) divisible vs. none–divisible technologies. Parvan argues that the first option involves an "internal deliberative process" but he also mentions how it is ultimately manifested as a dichotomous decision, and the aggregate adoption behavior can be observed as the diffusion of technology, and its corresponding adoption, throughout a discrete space. He clarifies too, how individual adoption can be measured to the degree of overall use, but it is ultimately a binary observation. Aggregate adoption, at its turn, says Parvan, can be measured as the aggregate level of use of a particular technology among one specific group of farmers, or within one particular area. He concludes that in most cases, agricultural technologies are introduced in bundles, and these bundles are often complementary (Parvan, 2011).

Finally, researchers like Place & Swallow (2000), focused their study on the positive influence of property rights over technology adoption. Sebeko (2015) describes the links between supply chains and the importance of credit for collective adoption of marketing strategies and technologies on behalf of small farmers to reduce food waste.

## 3.2 Agricultural Credit

First, it is basic to understand the existing relationship between agriculture commodity prices such as cacao and agricultural credit markets. In this regard Ftiti, Kablan, and Guesmi (2016), state that commodity price upturns increase liquidity in monetary markets, which leads banks to be more flexible in lending. Then commodity exports drive up credit. This, according to the authors, occurs whenever the prices of commodities – like cacao – scale, while the reverse arises when it decreases. These authors found that there is a strong positive relation between credit markets and commodities prices changes (Ftiti, Kablan, and Guesmi, 2016). It is pertinent to add as a definitive connection, that agriculture heavily depends on credit more than other sectors of the economy because of the seasonal variations of farmer's income and the support it requires to move towards commercial and industrial farming (Atiase et al., 2018). Authors such as Rogers (1995) have also stressed how credit affects technology adoption decisions on behalf of cacao farmers.

According to Dercon and Christiaensen (2011), agricultural credit plays an important role in boosting the growth of the agricultural sector for its connections with solutions to low agricultural productivity and poverty-reducing strategies. All efforts aimed at transforming smallholder agriculture from its subsistence nature to commercial and market-oriented farming require access to adequate financial resources. Access to credit, helps farmers to acquire necessary farm inputs and technologies as well as make strategic investments in their farms, mostly value-adding activities, and accessing better market opportunities that mean higher returns. As stated similarly by Tadesse (2014) credit facilitates farm households to enhance their capacity to effect long–term investment in their farms. Dercon and Christiaensen (2011) have also concluded that credit is not directly related to the purchase of agricultural inputs such as fertilizers considered -as it is well-known- as a type of technology. They found out, following the previous conclusions of Boucher et al. (2008) that individuals with lower asset levels opt-out of credit contract for the fear of losing their remaining collateral and because this type of credit – most of the time tied to fertilizer purchase – include very harsh enforcement mechanism to ensure the repayment (Dercon and Christiaensen, 2011).

Finally, on this component, the research of Giné & Yang (2008) established that farmers with higher educational levels tended to better understand loan requirements and seek credits actively. These findings are similar to the ones of Sajjad and Nasreen (2016).

Taking all of these factors into account, a closer look into Colombian agricultural credit figures is pertinent:

*Table 2. Credit for Colombian cacao producer from 2014 to 2018. Credit purpose.*

| Credit purpose | Periods | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | |
| | # of credits | Amount -In euro- | # of credits | Amount -In euro- | # of credits | Amount -In euro- | # of credits | Amount -In euro- | # of credits | Amount -In euro- |
| INVESTMENT | 7.426 | 20.051.767 | 10.397 | 29.416.499 | 11.167 | 33.786.359 | 11.599 | 39.762.366 | 4.891 | 17.334.224 |
| SUSTENANCE | 176 | 215.088 | 210 | 327.213 | 255 | 340.264 | 379 | 546.023 | 350 | 542.369 |
| RENOVATION – "CUP" TRANSPLANTATION | 83 | 178.471 | 162 | 421.220 | 95 | 312.849 | 114 | 324.857 | 94 | 266.184 |
| RECOVERY OF COCOA AREAS | 114 | 225.868 | 119 | 252.579 | 255 | 628.069 | 471 | 1.294.174 | 247 | 730.293 |
| CACAO RENOVATION | 88 | 236.300 | 62 | 166.180 | 31 | 109.516 | 86 | 238.792 | 63 | 172.773 |
| **Total** | **7.887** | **20.907.494** | **10.950** | **30.583.691** | **11.803** | **35.177.057** | **12.649** | **42.166.212** | **5.645** | **19.045.843** |

*Source: Self–made at Nov/2018 currency exchange rate, with the information provided by FINAGRO (2018).*

The main financing entity canalizing both private and public resources to the cacao producer through credit in this country is, The Fund for the Financing of the Agricultural Sector, FINAGRO, that possess relatively no outstanding financial indicators to solve on its own the lack of financing options for this segment of the population (FINAGRO, 2014). Specifically, the type of credit aimed to acquire technology and/or to strengthen management practices in the cacao production at the farm level. As presented in *table 3* the majority of money form credits goes to the investment the farmers required to guarantee the production. This investment could potentially be the purchase of machinery, equipment, infrastructure, even lands and animals purchase, many other types of investment (see *appendix A).* Nevertheless, the available data does not provide information on the specific end of these resources. The second item where most of the credit money is invested, the one known as "recovery of cacao areas", as shown in Table 2, related to soils adaptation, acquisition of seeds or plant material, planting, fertilization, technical assistance, weed and phytosanitary control, irrigation supply, and evacuation, road infrastructure, cover crops or shade crop and its support in the unproductive period and land lease when paid directly to the owner (FINAGRO, 2016).

During 2017 cacao producers all over Colombia received from FINAGRO (2018) credits amounting to 153.8 million Colombian pesos (COP), equivalent to 42 thousand Euros (How this amount was calculated can be seen in *Table 3*). The average of total credit per year during the last 4 years is around 32 000 Euros. This shows a low availability of resources: if this figure is divided among the total number of cacao producers – around 37 000 –, it can be stated that each producer could only receive less than a thousand euros per year – 864 Euro per farmer per year, on average, to be exact – assuming they all have access to credit, which is not true. To be more precise, a look into the composition of lenders is necessary:

*Table 3. Credit for Colombian cacao producer from 2014 to 2018. Farmer type*

| Producer Classification- Chapter - Production Line | | | Períods | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2014 | | 2015 | | 2016 | | 2017 | |
| | | | # of credits | Amount -In euro- | # of credits | Amount -In euro- | # of credits | Amount -In euro- | # of credits | Amount -In euro- |
| BIG | **Total** | | **1** | **398** | **2** | **488** | **4** | **156** | **4** | **3,516,404** |
| | Investment | **Total** | **1** | **398** | **2** | **488** | **4** | **156** | **4** | **3,516,405** |
| | | SOWING | 1 | **398** | 2 | **488** | 4 | **156** | 4 | **3,516,406** |
| MEDIUM SIZE | **Total** | | **180** | **1,258,728** | **391** | **3,142,689** | **242** | **3,554,271** | **237** | **2,588,846** |
| | Labor capital | **Total** | **5** | **13** | **10** | **83** | **4** | **9** | **8** | **33** |
| | | SUSTENANCE | 5 | 12,865.4 | 10 | **83** | 4 | **9** | 8 | 33 |
| | Investment | **Total** | **175** | **1,245,863** | **381** | **3,059,272** | **238** | **3,545,411** | **229** | **2,556,191** |
| | | SOWING | 175 | 1,245,863 | 381 | **3,059,273** | 238 | **3,545,412** | 229 | 2,556,191 |
| SMALL | **Total** | | **7.706** | **19,184,765** | **10.557** | **26,856,765** | **11.557** | **31,355,496** | **12.408** | **35,927,601** |
| | Labor capital | **Total** | **171** | **202** | **200** | **243** | **251** | **330** | **371** | **512** |
| | | SUSTENANCE | 171 | 202 | 200 | 243 | 251 | 330 | 371 | 512 |
| | Investment | **Total** | **7.535** | **18,983,222** | **10.357** | **26,614,004** | **11.306** | **31,025,167** | **12.037** | **35,415,961** |
| | | SOWING | 7.535 | 18,983,222 | 10.357 | **26,614,005** | 11.306 | 31,025,167 | 12.037 | **35,415,962** |
| **Total** | | | **7.887** | **20.907** | **10.950** | **30.583** | **11.803** | **35.177** | **12.649** | **42.166** |

*Source: Self–made at Nov/2018 currency exchange rate, with the information provided by FINAGRO (2018).*

As shown in *table 3*, most of the FINAGRO offer is taken by small farmers performing the sowing phase of cacao cultivation. Still, the figures show how small the overall amount of credit resources are; considering mainly the cost structure of this crop, it is understandable how insufficient these types of credits can be for a cacao farmer:

On the one hand, the entrance cost for one hectare in Colombia is around 4000 Euros. On the other hand, the total production cost varies from 1000 the first year to 2200 during the 6$^{th}$ year. These costs can increase when dealing with clon species (Barón Urquijo, 2016).

Information contained in *Table 2* and *Table 3* also allows concluding that the Colombia credit market does not offer any type of product designed specifically to promote improvement of management practices or technology adoption. Another important finding states that credit access constraint can be overcome easily when a farmer relies on a strong social – family and friends – network (Okten & Osili, 2004).

# 4. Method and data

This section explains in detail the methods. It followed two steps. The first step aimed at developing a farm typology by technology adoption. The second step aimed at explaining farms' technology adoption by a number of theoretically motivated independent variables, including access to credit.

## 4.1 Empirical Step I: Cluster analysis to identify farm technology choice

A suitable method to identify similarities among different farms agricultural practices was required. One procedure to identify the possible relations between technology adoption and agricultural credit is through the understanding of agricultural practices and farms characteristics.

As management practices present on a specific crop can be used to explain the total technology being used within a farm, are complex decision made by farmers (Suresh, Gajanan and Sanyal, 2014), and this complexity -as it is has been show in the literature review and in the results (sections 4 and 5)- is related to the fact that they do not rely on a single factor like capital or budget constraints, but instead on an arrangement of material and immaterial circumstances that change from farm to farm, like factors such as farm size, farmers social network, female participation in the farm decisions and access to credit, among others, the research required a mechanism to identify such practices.

It was decided that Cluster Analysis was the right way to pursue this data treatment goal, because compared with other tools such as an index construction, or direct regression analysis, data points gathered under clusters are considered to be -depending on the type of cluster validation- a "unsupervised classification". This means that it includes no predefined classes and the purpose of this method is to find which of them within a set are similar (Romesburg, 2004) ; the chosen method also makes the interpretation of results more simple by allowing the researcher to visualized the data points distribution and the different clusters they are located in. By using this method is also possible to prove the results increasing or decreasing the number of clusters to be analysed.

What this data treatment procedure causes once used upon a set of variables, is identifying the objects (points, data) with similar characteristics. When the purpose of a research is to understand how the objects in a same group are more similar to each other, and compared to those in other groups it is common to use Cluster analysis as a method because it also allows the identification of the underlying structures in the data, to summarize behaviors or characteristics, assign new individuals to groups and, to detect totally atypical objects (Rakotomalala, 2017). The selection of cluster analysis methodology responds as well to the fact that when the data was collected all variables were registered in a mixed table that contained quantitative and categorical information.

The Gower's metric similarity index algorithm (one of the ways to perform the cluster analysis) was a suitable fit to be used because it generates a series of cluster possibilities and further evaluates the appropriate number of clusters based on a high similarity index, establishing as a rule that, one additional unit in the number of clusters must represent at least an increase of 5% in the similarity index. The final number of clusters must provide also practicality regarding to an appropriate explanatory analysis.

As mentioned, since the data had already been collected at the time of the selection of the research topic, the analysis is limited to the scope accounting for management practices and technology adoption defined by the literature review and available in the data set.

Due to the nature of the data for statistical analysis, potential multicollinearity concerns emerged. They are addressed and tested at the end of the analysis performing a couple of robustness tests, like Silhouette methods addressed in the results section.

As this research looks into the impact of credit on technology adoptions, the "Management practices" on behalf of the cacao farmer were set as criteria to perform the cluster analysis to create the dependent variable resulting from a group of characteristics similar between the observed farms. These similarities would determine cluster membership. The outcome of the cluster analysis determined that two clusters were the best option to undertake the further steps of the empirical component. As the dependent variable is composed by a set of 1 and 2 numbers, it could not be computed as a natural number but as a binary option, meaning membership to cluster 1 and membership to cluster 2 when a cacao farmer belongs to this larger group. (*see Figure 3*)

To conclude this explanatory component of the section it can also be said that the Cluster analysis implemented in this research follows the basic concept of Sum of Squared Errors (SSE) and K-means (also understood as recompute the centroid of each cluster) to interpret the cluster results. The SSE formal and general definition can be noted as follows (Pang-Ning Tan et al., 2006) :

$$\text{SSE}= \sum_{i=1}^{k} \sum_{x \in c_i} dist\ (c_i\ x^2) \tag{1}$$

Considering these assumptions, it should be noted that the centroids that minimize the SSE of the cluster is the mean, the centroid (mean) of a given cluster is defined by the following equation (Pang-Ning Tan et al., 2006):

$$C_1 = \frac{1}{m_1} \sum_{x \in c_i} x \tag{2}$$

## 4.2 Empirical Step II: Explaining farms' technology choice and agricultural practices

Considering that the independent variables are all the factors that according to literature explain all relevant agricultural practices accounting for technology adoption measured in this research, both the dependent and independent variables are measured using a series of indicators obtained as direct information from the households who answered the questionnaire used to obtain the data (*see appendix B*). *Table 4* explains in detail which indicators compose the technology adoption variable.

This analysis included the following steps:

a Regression Analysis using a logit model was utilized. As the dependent variable, agricultures practices accounting for technology choice, is a binary one, within the many possibility's that this method offers the logit/probit model is the one that adjust better for these parameters.

The model representation function can be presented using the standard logistic regression model (Rodriguez, 2016) with the form of a general likelihood function.

Regression analysis estimates correlation and covariance between variables, helping to formulate questions for further examinations. In the case of this research the regression analysis was used to determine the influence of credit used over the two group of farmers, using membership to cluster number 1 as dependent variable: a new binary variable that took the value of one for one cluster, and the value of zero for the other (cluster 2) was introduced for this purposes, and then regressed against factors accounting for tech Adoption (obtained from literature review).

The variables used as regressors or independents variables are described in *table 4*. A set of 4 regression was perform assuring their robustness. This component of the research is explained in detail in the results sections.

## 4.3 Data

The data set used for the analyses contains information on agronomic practices, social-economic conditions, environmental conditions, and farmers' motivations. It was collected by interviews using a questionnaire (*Appendix B*) designed by the agronomist Cristian Leonardo García, who collected the data that was also built with the information provided by a local farmer's association. Each sampled household was interviewed once. It utilized multi-year sales reports from the local cooperative. The reports contained a gross quantity of dry cacao beans sold by the year, as an estimate of productivity calculated by the number of hectares of each producer. Survey application took place in the cacao producer households: The main variables were sorted from the database containing the information collected in the abovementioned survey and are described below.

Data from soil features and classification were obtained from the Geographical Institute Agustín Codazzi –IGAC– based on a complete study of soils of Tolima in which was directly correlated with each farmer's location overlaid in a composed data frame. Additional geographic information was obtained from CGIAR– CSI Consortium for Spatial Information (García, 2017).

Out of 169 variables available in the dataset, 72 were chosen initially. After including the "management practice" criteria, 20 variables were dismissed for the sake of the model coherence. For the initial cluster analysis, 49 variables were selected:

*Table 4. Description of variables chosen from the data set*

| Variable name in the dataset ( long and short names) | Variable description | Variable Type / Categories |
|---|---|---|
| 1. *Credit use* / DV_agCredt | The farmer has or had a credit aim for his/her cacao/farm crops | Logic: True/False |
| 2. *Gender* /frGender | No description needed (NDN) | Text: Female/Male |
| 3. *Farmers Expertise* / TA_frExprts | Farmer expertise in cacao growing | Factor: Beginner/Trainee/Expert/Senior grower |
| 4. *Land Tenure*/ TA_ldTenure | For different authors, this condition is influenced positively by tech adoption. | Invader/Legal occupier/Legal owner/ Rent |
| 5. *Preferred buyer*/ prefer | To whom is the cacao farmers selling his cacao beans after the harvest | Text: Cooperative/Private Agency |

| | | |
|---|---|---|
| 6. *Distance to Agency/* dsAgency | NDN | Numeric: number of Km from the farm to the agency where the harvest is sold. |
| 7. *Financial Support* /finSuppt | Farmer gets any financial support from family members | Logic: Yes/No |
| 8. *Extension services*/ extSrvc | Farmer perception of extension service | Text: Absent/Barely present/ Constant |
| 9. *Social Security*/socSecur | Social security as a welfare indicator | Text: Public insurance/Private insurance |
| 10. *Local workers*/ TA_loclWrks | Farmer hires local workers | Logic: True/False |
| 11. *Spouse active*/ spsActv | Farmer's spouse is active in the farm | Logic: True/False |
| 12. *Family labor* /ES_famLabor | Family workforce including himself | Numeric. An entire number from 1 to 10 |
| 13. *Field Worker* / fdWkr | The farmer works as field worker outside his plantation | Logic: True/False |
| 14. *Lime use* / limeAppl | Farmer applies regular lime | Logic: True/False |
| 15. *No Lime applied* / noLime | Farmer does not apply lime | Logic: True/False |
| 16. *No use of fertilizers* /noFert | No fertilization at all | Logic: True/False |
| 17. *Organic Application*/ orgnAppl | Farmer uses organic fertilizers | Logic: True/False |
| 18. *Pesticides Use* / PestUse | Farmer uses pesticides | Logic: True/False |
| 19. *Soil affected by acidity* / aftdAcdt | Perception of the farmer about acidity problems | Logic: Yes/No |
| 20. *NPK use* /npkAppl | Farmer uses compound fertilizer | Logic: Yes/No |
| 21. *SoilpH*/soilpH | pH of the soil of plantation where the survey was applied | Numeric: from 0 to 14 |
| 22. *Area planted* /TA_areaPlan | Area of plantation with Cacao in the production stage in ha. | Number:0–100 |

| | | |
|---|---|---|
| 23. *Plant Density*/ planDens | Number of cacao trees per hectare | Text: A=<750/B=750-850/C=850-990/D=>990 |
| 24. *Agro Forestry Species* /agFrSp | NDN/ Number of Agro forestry species | Numeric: 0-10 |
| 25. *Shade %*/ shdPrcnt | Percentage of shading in plantation | Numeric: 10-100 |
| 26. *Farmer type*/ frType | Farmer type (according to Ministry of agriculture classification) | Text: Allied producer/Associated producer/ Independent producer |
| 27. *Production type* /prodType | Production type based on area | Text: Small producer/Rural woman/Median producer |
| 28. *Farmer produces Diary* /frDry | Farmer produces Dairy for additional income | Logic: True /False |
| 29. *Farmer grows Plaintains* / frPltn | The farmer grows plantains for additional income | Logic: True /False |
| 30. *The farmer grows Maize /*frMaize | NDN | Logic: True /False |
| 31. *The farmer grows Cassava* /frCassv | NDN | Logic: True /False |
| 32. *The farmer has Poultry* /frPltry | The farmer grows poultry for additional income | Logic: True /False |
| 33. *The farmer grows Coffee*/ frCoffee | NDN | Logic: True /False |
| 34. *The farmer grows Bananas* /frBanana | NDN | Logic: True /False |
| 35. *Vegetable Orchard* /frVegOrc | The farmer has a Vegetable orchard | Logic: True/False |
| 36. *Food Security*/ FoodSec | Addition of the number of products the farmer grows for self-consumption | Numeric. |
| 37. *Sewage System* / TA_sewageS | Type of Sewage system used in the farm | Text /Biodigester/Latrine/None/Toilette connected to septic tank/Toilette connected to a sewage network |

| | | |
|---|---|---|
| 38. *Pruning type/* prunType | NDN | Text / F=Formation pruning/M=Mainteniance pruning/S=Sanitary pruning |
| 39. *Machete use* /TA_frMachet | Farmers utilize machete | Logic: True/False |
| 40. *Scissors use*/TA_frSccisr | Farmer uses scissors | Logic: True/False |
| 41. *Gloves use* / TA_frGloves | Farmer uses gloves | Logic: True/False |
| 42. *Healing paste use* TA_frHealP | Farmer uses healing paste for grafting procedures | Logic: True/False |
| 43. *Plastic tape use*/ TA_frPlastT | Farmer uses plastic tape for renewing and pruning processes | Logic: True/False |
| 44. *Altitude* | The altitude of the farm in meters above sea level. | Numeric. |
| 45. *Income source* /incomeSr | Additional income sources besides cacao growing | Text / C=Coffee/T=Cattle/F=Field worker/O=None/P=Plaintain/ |
| 46. *External income* / extIncom | The farmer has any additional source of additional or substitute income | Factor: True/False |
| 47. *Yield 2015* /y2015 | NDN | Numeric / Mg/ha. |
| 48. *Tools use* / TA_ToolsUse | Addition of the total number of tools used by the farmer | Numeric |
| 49. *Conflict victim type* /cnflcVic | Conflict victim (National Government classification) | Text / Abandoned/Displaced by violence/Disposed of his property/No victim/relative of forced disappearance/Terrorist attempt/Under threat |

*Source: Self-made.*

The database has a strong component of agronomy features providing suitable variables for this research, especially from the perspective of the study and selection of management practices as the dependent variable.

The sample selection procedure was performed to a group of farmers that was selected for the application of a multi-approach survey. The number of farmers was the result of a filtering process of individuals who fulfill a specific list of conditions as below:

- Farmers with farms located inside the land consolidation zone
- Farmers registered in FEDECACAO and Coffee farmer's cooperative
- Farmers who have been selling cacao beans to the cooperative regularly
- Farmers who have participated actively in productive enforcement programs, to assure they remain active as cacao producers. The filter gave as result a list of 500 households from which a sample of 121 farmers (24.2% of the total population) was randomly selected (Garcia, 2017).

# 5 Analysis, results and discussion

This section presents the results of the empirical component of the research. The cluster and the regression analyses are presented in sections 5.1 and 5.2 respectively. These results are the basis to establish the discussion here contained and as well as the conclusions and policy recommendations.

## 5.1 Cluster analysis to identify farm technology choice

The variables chosen to perform the cluster analysis are directly related to management practices within the farm. Variables such as food security, the children, local workers or spouse contribution to the labor factor were available in the database and were selected as factors that can provide a more detailed account of management decisions made by the cacao farmers. The area planted with cacao, the availability of a sewage system, the total number of tools used at the farm, were also considered as variables that together can explain how prone these farmers are to adopt technology. The variable measuring pesticides use, phosphate application on the cacao fields, the use of organic fertilizers or the presence of cattle selection followed the same selection logic.

The first step was to select a group of variables accounting for management practices (most of the variables 10 to 26 on *table 4*) for example: 1. Availability of local workers, 2. Spouse active, 3. Family labor; 4. Field Worker ; 5. Lime use; 6. No Lime applied; 7. No use of fertilizers; 8. Organic Application; 9. Pesticides Use; 10. Soil affected by acidity; 11. NPK use; 12. Soil pH; 13. Area planted; 14. Plant Density; 15. Agro-forestry Species; 16. Shade percentage; 17. Farmer type, and 18. Production size.

Then, within the frame of the cluster analysis, using the statistical software R, the first procedure performed was computing and visualizing the k-distance matrix, after that the k-means clustering were calculated (UC Business Analytics, n.d.). After completing those two initial procedures, the use of different methods suggested to perform the cluster analysis (Gower, 1971): 1. Compute Gower distance, 2. Visualize the most similar variables, 3. Compare a different set of clusters by generation plots to assess the best options. 4. Computing the optimal number of clusters using Elbow, Silhouette and GAP methods (Tibshirani et al., 2000), also used as robustness test, was then the next step. Before concluding, computing the k-means clustering using the two cluster option (as suggested outcome from the mentioned procedures) and visualizing the results were the previous steps before the creation of a cluster membership variable.

After applying all of the mentioned methods, K-means clustering with 2 clusters of sizes 94, 27, was the outcome. After computing the mean of the described variables, it was necessary to compare a different set of clusters and observe them estimate how the data points distances gather, match or overlap within each possible group (Kaufman and Rousseeuw,1990; Tan et al., 2019). Cluster results for technology adoption factors are shown in *figure 3.*

Average silhouette width indicates the similarity index if a specific number of clusters is selected (Gower, 1971). The silhouette method suggests 2 as the optimal number of clusters. However, it should be considered that not only a higher index but an increase in one unit in the number of clusters must represent at least 5 % of the variation in the already mentioned index as a condition to be selected. This condition is observed when the number of cluster shifts from 2 to 3. Additionally, for the sake of practicality and considering data-set limitations, 2 clusters were selected as the adequate number of groups based on the notorious difference between clusters that can explain farmers behavior in terms of group segregation by variable. Two clusters resulted on a similarity index of 45 % that can be considered as suitable to deal with the habitual trade-off between exactitude and practicality.

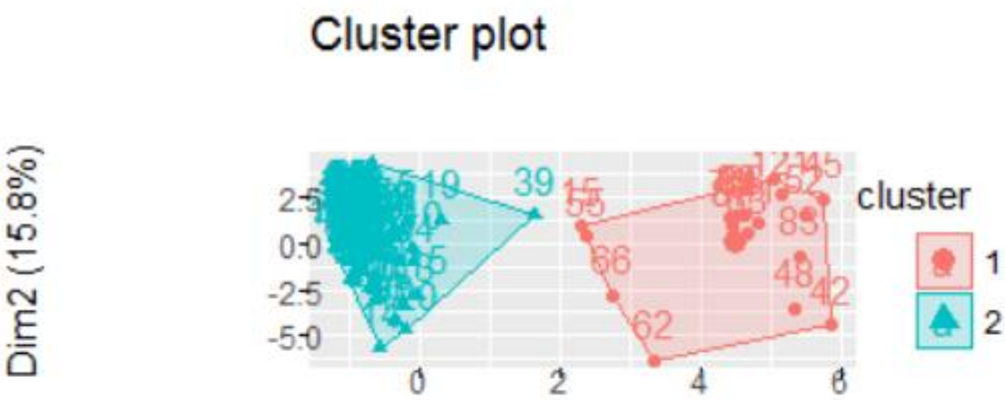
As a result of the cluster analysis, it was also observed that the higher the number of clusters, the higher the cluster means percentage (*ss_total* outcome on R software) that represents the compactness of the clustering, and the lower the *within sum of squares* accounting for dissimilarities between the members of a group (Gower, 1971). This type of outcome is expected when utilizing this type of method.

Cluster 1 member represent 15.7 % of the sample (n=19), and is characterized by the farmers who have neither understanding of nor interest in coherent management of their cacao plantations, and therefore do not invest resources on it. This cluster can be described as a group of farms characterized by an above-average use of tools (0.25), a low average of offspring's participation in the crop activities, and an above-average (0.73) female participation in the farm businesses. One characteristic that makes this group deviate from cluster number 2 is their low technical knowledge or expertise/interest in cacao farming. This is shown by the high number of farmers not practicing any type of pruning on their crops, even this practice is very important for the quality outcome of the cacao harvest (Govindaraj & Jancirani, 2017).

The Cluster 2 is represented by 84% of the sample (n=102). These are the farmers who have an adequate level of understanding about agriculture business and cacao farming. They were characterized by performing all the necessary management and agronomical practices – such as pruning – .These are farmers that are willing (or able) to spend resources or time in the purchase and/or application of fertilizers and lime. The overall observation obtained after cluster analysis allows concluding that farmers in cluster number 2 have a better education, training and they live in overall better social conditions than farmers from cluster number 1.

The previous final stage of this cluster analysis was to compute the optimal number of clusters using various methods. Then the 2 clusters plot was generated (*See also Appendix C*).

*Figure 3. Two Clusters option plot overview*




*Source: Self-made, on R.*

Summarizing, farms were divided into two groups based on their agricultural practices and the characteristics of their farms, where one group was formed by 'adopters'(cluster 2) and the other by 'non-adopters'(cluster1). Then, the effect of credit availability on the likelihood of a farmer joining the group of adopters was tested. A logic type of regressions (log) was performed after obtaining results from the cluster analysis. Three sets of regressions were undertaken. Their components, the dependent and independents variables selected were explained in detail and presented in section number 4.

## 5.2 Explaining farms' technology choice and the role of credit

After the clusters were stablished the regression process took place. As most of the variables – 40 out of 49 – both in the initial data-based and in the dataset finally sorted, were mainly categorical which implied the need to recode most of them into binary and numerical multilevel. Once the recode was made, it allowed the sort of the initial data selected from 71 variables into the final one containing 49. After dismissing the variables, variance inflation factors were undertaken to verify how those values superior to 0.5 were correlated. The results did not show any other significant correlations.

Considering other similar studies like the one of Taher, S. (1996), Ftiti, Kablan, and Guesmi (2016), Atiase et al. (2018), Rogers (1995) and Dercon, and Christiaensen (2011) and methodologies already used, 121 observations from small cacao producers were utilized, including variables such as the size of the farm, household size, farm size, sex of the cacao grower, years of education, credit access, among others already named and described in *table 4*.

The regression analysis followed an incremental logic – as part of the robustness tests (Neumayer and Plümper, n.d), meaning few variables were used first and some additional were introduced gradually in further regressions – using the membership to cluster number 1 as the dependent variable (Gelman, A. and Hill J., 2007). The first regression used the variables credit, gender, land tenure, and area planted (all of them mentioned in the technology adoption literature review as correlated positively to the final decision to adopt). This initial regression as the following ones tried to find out how the technology adoption factors could be explained by credit use, to prove or deny the main hypothesis in this research. As presented, none of the regression performed allows proving the main assumption as certain. Nevertheless, to describe some of these results is important. The outcomes were the following (*See appendix D*):

*Table 5. Area planted shows positive correlation*

| Variable | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 203.208 | 0.11725 | 17.331 | <2e-16 *** |
| DV_agCredt | -0.03710 | 0.04063 | -0.913 | 0.3631 |
| SS_frGender | 0.01562 | 0.05322 | 0.293 | 0.7697 |
| TA_ldTenure | 0.01968 | 0.02645 | 0.744 | 0.4585 |
| TA_areaPlan | -0.10344 | 0.00731 | -14.150 | <2e-16 *** |

*Source: authors calculations*

*Table 5* shows that the only independent variable having a positive correlation with the dependent one was the area planted, meaning that the management practices are influenced by the size of the cacao area that a farm has. And that those farmers having a bigger area planted are more prone to have access to agriculture credit.

*Table 6. Family labor show positive correlation*

| Variable | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 203.208 | 0.11725 | 17.331 | <2e-16 *** |
| DV_agCredt | -0.03710 | 0.04063 | -0.913 | 0.3631 |
| frGender | 0.01562 | 0.05322 | 0.293 | 0.7697 |
| TA_ldTenure | 0.01968 | 0.02645 | 0.744 | 0.4585 |
| TA_areaPlan | -0.10344 | 0.00731 | -14.150 | <2e-16 *** |
| ES_spsActv | 0.02544 | 0.04385 | 0.580 | 0.5630 |
| ES_famLabor | 0.04311 | 0.02439 | 1.768 | 0.0798 . |
| TA_loclWrks | 0.02456 | 0.04332 | 0.567 | 0.5720 |

*Source: authors calculations*

In the second regression, besides the area planted, the variable accounting for family labor also showed a small statistical significance. This can be interpreted as some incidence of family labor within better management practices referred to as the main characteristic of cluster 2. The high statistical significance for the intercept means that the expected value of Y will be 2.0 when all the explanatory variables means are centered or equal to zero. This is a good sign of the model coherence too.

*Table 7. Victim independent variable show small statistical significance*

| Variable | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 173.813 | 0.08606 | 20.197 | <2e-16 *** |
| cnflcVic | 0.04740 | 0.02775 | 1.708 | 0.0902 . |

*Source: authors calculations*

For the coherence of the practical part with the empirical one, the variable accounting for farmers that were victims of the armed conflict was also considered in further regression. It showed a small statistical significance.

Access to agriculture credit and gender (being female), two factors that according to literature, impact positively technology adoption, showed no correlation when regressed against good management practices. Regressing the dependent variable against only one variable (like the conflict victim one) or set of variables and regressing the dependent variable changing the sample number were procedures done as robustness tests. None of them turned with special outcomes as seen in Appendix C.

Finally, a couple of regression using variables representing both labor and capital intensiveness were performed. Only the second one showed significant statistical results:

*Table 8 Farm size relevance in cluster # 2*

| Variable | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 2.32423 | 0.41540 | 5.595 | 1.56e-07 *** |
| DV_agCredt | -0.04379 | 0.06853 | -0.639 | 0.52415 |
| TA_ldTenure | 0.05086 | 0.04288 | 1.186 | 0.23806 |
| prodType | -0.33451 | 0.11521 | -2.903 | 0.00444 ** |
| orgnAppl | -0.15501 | 0.16853 | -0.920 | 0.35963 |

| | | | | |
|---|---|---|---|---|
| TA_sewageS | -0.02402 | 0.02327 | -1.033 | 0.30400 |
| TA_ToolsUse | -0.02366 | 0.03286 | -0.720 | 0.47307 |
| PestUse | -0.13347 | 0.34021 | -0.392 | 0.69557 |

*Source: authors calculations*

The variable "Production type" represents if a farmer is part of the sample belonging to the small producer, the rural women, or the medium-size producer. The fact that this variable showed high statistical significance, considering the already described characteristics of the cluster number two, can be interpreted as a sign of the relation of the size of the farm with the group of better agricultural practices. This result is in tune with the literature and with the Colombian farmland, tenure structure discussed further in detail here below in the coming subsection.

To conclude this results analysis component, it is capital to mention that as shown on *table 3* vast majority of agriculture credits have as final destination the pockets of small farmers, who according to the results here presented are not the ones with the better agricultural practices. This shows a relevant disconnection between credit provision and extension services.

## 5.3 Discussion

Technology adoption is a key challenge in agriculture (Doss, 2006). The question of this master research is whether farmers' agricultural practices/technology adoption is driven by their access to capital. Results showed that capital-constrained farmers may use more labor-intensive means of producing than they would like to. Another important finding is the clear difference between credit receptors (mainly small farmers members of cluster 1) and the group of farmers with better management practices. The results compared with the data about credit proves the need of much better extension services tight to the approval of agriculture credit which at the moment of the study do not seemed be connected.

It could be stated, remembering what Sunding and Zilberman (1999), said about management practices, categorizing then as a type of agronomic innovation, that, after observing the results it is clear how those farms showing the best management practice tend to be more innovative and can be located in the group of technology adopters. This connection explains the deep existing link between management practices–innovation and technology adoption.

The above presented result also coincide with some of Taher (1996) and Parvan (2011) assessments and conclusions, as presented in the literature review section: Family workforce-described as human capital and labor availability in Parvans research-, and Farm size are factor that also appear to be important for technology adopters under the light of this research. The second authors also mentioned capital constraints and tenure as decisive factor for technology adoption in the same manner this master research does.

### 5.3.1 Agriculture credit and land tenure

The current state of the world cacao market facing challenges and lacking equity for its farm-level workers was presented in the introduction of this work and becomes relevant when analyzing the results. As expected, and in line with some of the most common findings in the literature, it could be said that agriculture credit in Colombia is not bringing along easier and more steady extension services and is granted more to farmers not far away from the markets. Land tenure does not seem to be a condition explaining how farmers have access to such credits.

This is of major relevance in a country where tenure is highly unequal – 2,055 landlords own farms exceeding 2000 hectares that represent only 0.06% of all the total owners of the country, accounting for 51.5% of the Colombian agricultural area (Segrelles Serrano,2018) – and where its property has shaped the last half-century of violence that does not seem to end:

> The unequal distribution of land ownership in Colombia and consequent rural poverty is the main cause of the armed conflict that has beset the country for over fifty years. The concentration of land ownership in the hands of the few, the power wielded by agribusiness and farmers and the predominance of a farming system aimed more at export than at domestic consumption, all urge a reform that goes beyond mere land redistribution: land ownership must be democratized by providing small farmers with access to supplies, credit, and technical assistance, as well as infrastructures, education, housing, and health. The new agricultural and rural legislation brought in during the peace process to help in the post-conflict era is incomplete, presents many limitations and does not substantially address the root of all the problems: the land ownership structure (Segrelles Serrano,2018, p. 409).

Results add some other features yet to explore deeper, for example, the positive influence keeping records of fertilizers applications and hiring of local workers as indicators of better management practices.

These outcomes are also in line with Place & Swallow (2000) findings about the positive influence of property rights as a relevant technology adoption factor in line with Segrelles Serrano statement: considering these finding, it can be said that as long as Colombia remains in it shameful position as one of the countries with the highest land tenure inequity on Earth, no significant progress for the majorities of citizens living in rural areas would be reached.

### 5.3.2 Social factor accounting for technology adoption

Besides the unexpected statistical insignificance of agriculture credit it should be mention, even when it could be considered logic and it is not present in the literature findings, that the statistical significance of the variables related to capital such as production type and area planted should also be described as one of the most important characteristics of a small and medium-size type of agriculture farming, always described in literature and found also relevant in this research again. This results support the initial perception of the relation among variable formulated in the conceptual framework.

For the coherence of the practical part with the empirical one, the variable accounting for farmers that were victims of the armed conflict was considered and it did show statistical significance. These facts can simply represent that being a conflict victim influence positively the adoption of technology and/or the performance of better management practices – the dependent variable – which is understandable considering that compared to regular farmers those who are conflict victims and are located in former conflict areas as South Tolima region tend to receive more support from governmental institutions, programs and extension services.

# 6 Conclusions and recommendations

## 6.1. Policy Recommendations

*"A value chain that accepts structural poverty as inevitable can never be called sustainable* (Fountain and Huetz-Adams, 2018, p. 13)".

This research showed that farmers with larger areas also had a higher chance of having access to agricultural credits (*Table 5*). Policy makers could develop programs targeting small farms to increase access. The research results also point towards a weak state in the important and well-known connection between credit access and technology adoption within the cacao production of the farmers from the south Tolima region in Colombia from the credit use and management practice perspectives which is in line with other literature (Giné & Yang, 2009).

Following the findings of the present research the Colombian government should also offer more incentives to groups of small farmers (like the members of cluster number 1), mainly in the form of extension services since it can improve their knowledge about better management practices and increase their chances to access agriculture credit and adopt innovative procedures to make their productive process more efficient.

Considering the additional evidence presented in this document around family labour involved in the cacao farming in the south region of Tolima (*Table 6*), the provision of more extension services for these farmers is a suitable policy recommendation. This research does not show that farmers families are less trained but the data collected allows to conclude that their income for external activities is minimum. Discounting the existing need for better roads and infrastructure that must be delivered by the Colombian National Government preside in this sector by the Ministry of Agriculture, it is the duty of national entities such as FINAGRO and AGROSAVIA along with the participation of cacao sector stakeholders such as FEDECACAO and chocolate production companies and exporters, to deliver these services and also to design and make available new financial tools to support farmers along the different stages of cacao cultivation, so they can perform their activity in a more efficient way allowing their families to be less involved in the production, making possible for those family members (spouse and children) to take part of off-farm activities to improve their income and their education levels.

Taking into account the reflection around land tenure stressed in the discussion and measured also in the analytical part of this research (*Table 8*), to provide agriculture credits aiming to boost technology adoption which access is less dependent on land tenure as a guaranty can only be provided by state-own entities able to take more risk than private banks. This is of capital importance to take action that ends up making cacao production in South Tolima region and in all the other 26 departments of Colombia where cacao is currently grown, truly sustainable, mainly from the economic and social perspectives. As one of the main policy recommendations emerged from the discussion, the Colombian government should also strengthen, deepen and enforce the tenure legalization national policy.

Results on *Table 7*, showing the victim independent variable small statistical significance make possible to stress that better agriculture practices linked to higher chances to adopt technology are more likely to be implemented by cacao farmers who are also conflict victims. To focus and strength the provision of agriculture programs including all the elements already mentioned, in the frame of the non-concluded implementation of the Habana Peace agreement as an legal and international obligation of the Colombian state is another important policy recommendation emerged from the results of this master thesis.

## 6.2 Limitations and future research

The main limitation of this master thesis was undoubtedly the fact that the data was already collected when the research design was approved. Added to the sample size, this could be the main reason why this research results do not provide clear-cut evidence supporting the initial hypothesis. For future research, it would be important to undertake the survey and data collection trying to follow as close as possible all the indicators and index constructions or similar ones referred to in literature.

Considering the importance of the open debate around direct and indirect subsidies for agriculture production and technical efficiency (Minviel and Latruffe, 2017) and the potential role they can play in technology adoption, they could be used instead of the management practice as dependent variables for future research. Future research using the same or a similar sample could be performed to study the effects of either credit or direct subsidies aiming to promote technology adoption using methods, such as Propensity Score Matching to investigate the impact of such policy before and after its implementation.

## 6.3 Conclusions

This research analysed the influence of credit used over technology adoption within cacao production in three different municipalities of the department of Tolima in Colombia. As presented, results do not show clear evidence of a positive and significant correlation between agricultural credit use and the main factors explaining technology adoption in cacao farming in those three municipalities. Nevertheless, the research results show how the hypothesis could hold true for the cases of farmers having better overall economic conditions represented mainly by the size of their farms and their tenure condition.

Besides this, along the research path, this thesis observed how extension services, public goods that shorten the distance to markets, formalization of land tenure and new types of credit that boost innovation and technology adoption need to be created and offered more proactively by state institutions in charge. It is very inefficient to provide credit and not link it with the provision of extension services.

The results also confirmed that from the broad perspective of sustainable agriculture, technology adoption role is still an open debate (Zilberman et al.1997) that encourages the deepest endeavour of our societies to thrive in the path of a more clean and equitable system of food production worldwide. To achieve this goal, academic and practical knowledge, scholars and farmers of all kinds should work together to use the current scientific wealth of information as a primary tool to solve the most urgent issues of the citizens providing food for everyone. Without the synergy emerging from the team effort of all the stakeholders involved in the "field to fork" value chain, it would be impossible to bravely deal with the threat that the climate crisis imposes to the very existence of our species.

# References


Acosta Bonilla, S. C., & Villarraga Rubio, M. V. (2006, March 1). *Diagnostico tecnológico del cultivo de cacao (theobroma Cacao) en el Municipio de El Dorado, Departamento del meta (Col.)*. Villavicencio, Colombia. Retrieved October 9, 2019, from

Arias, J. (2016, February 1). The Contribution of Agriculture to Development. *IICA*. Retrieved October 9, 2019, from https://www.researchgate.net/profile/Joaquin_Arias/publication/298793336_The_contribution_of_agriculture_to_development/links/56ec2f3908aed17d09f63f3c.pdf

Atiase, V.Y., Mahmood, S., Wang, Y. and Botchie, D. (2018), "Developing entrepreneurship in Africa: investigating critical resource challenges", Journal of Small Business and Enterprise Development, Vol. 25 No. 4, pp. 644-666. https://doi.org/10.1108/JSBED-03-2017-0084

Barón Urquijo, J. D. (2016). El cultivo del cacao; un Negocio rentable, competitivo y ambientalmente sostenible en Colombia. Retrieved October 9, 2019, from https://www.fedecacao.com.co/portal/images/Ing._Jos%C3%A9_David_Bar%C3%B3n_-_El_cultivo_del_Cacao_un_negocio_rentable_competitivo_y_ambientalmente_sostenible_en_Colombia_2016.pdf

Bizikova, L., Brewin, S., Bridle, R., Laan, T., Murphy, S., Sanchez, L., & Smaller, C. (2020). *The Sustainable Agriculture Transition: Technology options for low- and middle-income countries* (p. 35).

Boucher, S. R., Carter, M. R., & Guirkinger, C. (2008). Risk Rationing and Wealth Effects in Credit Markets: Theory and Implications for Agricultural Development. *American Journal of Agricultural Economics*, *90*(2), 409–423. Retrieved October 9, 2019, from 10.1111/j.1467-8276.2007.01116.x

Christiaensen, L., & Dercon, S. (2007). Consumption Risk, Technology Adoption, And Poverty Traps : Evidence From Ethiopia. Retrieved October 9, 2019, from 10.1596/1813-9450-4257

Doss, C. R. (2006). Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement. *Agricultural Economics*, *34*(3), 207–219. Retrieved October 9, 2019, from 10.1111/j.1574-0864.2006.00119.x

FEDECACAO. (2017). Economía Nacional. Retrieved October 9, 2019, from http://www.fedecacao.com.co/portal/index.php/es/2015–02–12–17–20–59/nacionales

FINAGRO. (2016). *Productos, Servicios E Incentivos – Administrados Por Finagro Para La Actividad. Condiciones Generales De Credito*. Bogotá.

Fountain, A., & Huetz-Adams, F. (2018). *Cocoa Barometer 2018* (p. 76). Cocoabarometer.org. Retrieved October 9, 2019, from https://www.voicenetwork.eu/wp-content/uploads/2019/07/2018-Cocoa-Barometer.pdf

Franzen, M., & Borgerhoff Mulder, M. (2007). Ecological, economic and social perspectives on cocoa production worldwide. *Biodivers Conserv*, *16*(13), 3835–3849. Retrieved October 9, 2019, from 10.1007/s10531-007-9183-5

Ftiti, Z., Kablan, S., & Guesmi, K. (2016). What can we learn about commodity and credit cycles? Evidence from African commodity-exporting countries. *Energy Economics*, *60*, 313–324. Retrieved October 9, 2019, from 10.1016/j.eneco.2016.10.011

Gelman, A., & Hill, J. (n.d.). Multilevel regression, 235–236. Retrieved October 11, 2020, from 10.1017/cbo9780511790942.014

Giné, X., & Yang, D. (2009). Insurance, credit, and technology adoption: Field experimental evidencefrom Malawi. Journal of Development Economics, 89(1), 1-11. doi:10.1016/j.jdeveco.2008.09.007

Jia, F., Zuluaga-Cardona, L., Bailey, A., & Rueda, X. (2018). Sustainable supply chain management in developing countries: An analysis of the literature. *Journal of Cleaner Production*, *189*, 263–278. Retrieved October 11, 2019, from 10.1016/j.jclepro.2018.03.248

National Administrative Department of Statistics DANE. (2015). *Informe de contexto del 3er Censo Nacional Agropecuario*. (p. 5). Retrieved from https://www.dane.gov.co/files/CensoAgropecuario/avanceCNA/CNA_Contexto_2015.pdf

Cristian Leonardo, G. M. (2017). *Multidimensional approaches for analyzing the variability of cacao productivity in post-conflict households in South Tolima, Colombia.* (Masters degree thesis). University of Bonn. Retrieved October 11, 2019.

García–Cáceres, R. et al. (October 2014). Characterization of the supply and value chains of Colombian cacao. Universidad Nacional de Colombia. DYNA 81 (187), pp. 30–40. Retrieved October 2019 from DOI: http://dx.doi.org/10.15446/dyna.v81n187.39555

Govindaraj K & Jancirani P (2017). Effect of Pruning On Cacao (*Theobroma Cacao* L) On

Gower J.C (1971). A General Coefficient of similarity and some of its properties. Biometrics 27, 857-871. doi: 10.2307 / 25 28823.

High Presidential Counseling for the Post Conflict. (2018). Sustitución de cultivos: llegó la hora del cacao. Retrieved October 2019 from http://www.posconflicto.gov.co/sala–prensa/noticias/2018/Paginas/20180418–sustitucion–de–cultivos–llego–la–hora–del–cacao.aspx

ICCO, I. C. O. (2017). Production of cocoa beans. Retrieved 2019, from https://www.icco.org/statistics/quarterly-bulletin-cocoa-statistics.html

Kaufman, L., & Rousseeuw, P. J. (2009). Finding Groups in Data: An Introduction to Cluster Analysis. Wiley. New York, New York: Wiley. Retrieved 2019, from https://www.wiley.com/en-us/Finding+Groups+in+Data%3A+An+Introduction+to+Cluster+Analysis-p-9780471735786

Lee, D. R. (2005). Agricultural Sustainability and Technology Adoption: Issues and Policies for Developing Countries. American Journal of Agricultural Economics, 87(5), 1325–1334. Retrieved 2019, from https://doi.org/10.1111/j.1467-8276.2005.00826.x

Microenergie International (2017). Diseño de Productos microfinancieros enfocados a brindar soluciones tecnológicas a productores de cacao y fortalecer la cadena de valor del sector. Berlín: Germany Working paper not published.

Ministry of Agriculture of Colombia (2018). El sector agropecuario mantiene un crecimiento positivo con una variación de 2% en el primer trimestre de 2018. Retrieved from https://www.minagricultura.gov.co/noticias/Paginas/El-sector-agropecuario-mantiene-un-crecimiento-positivo-con-una-variaci%C3%B3n-de-2-en-el-primer-trimestre-de-2018.aspx

Minviel, J. J., & Latruffe, L. (2016). Effect of public subsidies on farm technical efficiency: a meta-analysis of empirical results. Applied Economics, 49(2), 213–226. Retrieved 2019, from https://www.tandfonline.com/doi/full/10.1080/00036846.2016.1194963

Mwangi, M., & Kariuki, S. (2015). Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries . Journal of Economics and Sustainable Development, 6(5). Retrieved 2019, from https://www.iiste.org/Journals/index.php/JEDS/article/view/20710

Neumayer , E., & Plümper, T. (0AD). Robustness Tests for Quantitative Research. polsci.org. Retrieved 2019, from http://www.polsci.org/robustness/robustness.pdf

Ntiamoah, A., & Afrane, G. (2008). Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach. Journal of Cleaner Production, 16(16), 1735–1740. Retrieved 2019, from https://www.researchgate.net/publication/222833066_Environmental_impacts_of_cacao_production_and_processing_in_Ghana_life_cycle_assessment_approach

Obuobisa-Darko, E. (2015). Credit Access and Adoption of Cacao Research Innovations In Ghana. Research on humanities and social science , 5, 16–24. Retrieved 2019, from https://www.semanticscholar.org/paper/Credit-Access-and-Adoption-of-Cocoa-Research-in-Obuobisa-Darko/397acb2345cf21457377e1f57d7c398a8e5037dc?p2df

Ortiz-R, O. O., Gallardo, R. A. V., & Rangel, J. M. (2014). Applying life cycle management of colombian cocoa production. Food Science and Technology, 34(1), 62–68. Retrieved 2019, from https://www.scielo.br/scielo.php?pid=S0101-20612014005000006&script=sci_arttext

Okten, C., & Osili, U. O. (2004). Social Networks and Credit Access in Indonesia. World Development, 32(7), 1225–1246. Retrieved 2019, from https://www.sciencedirect.com/science/article/abs/pii/S0305750X04000634

Parvan, A. (0AD). Agricultural Technology Adoption: Issues for Consideration When Scaling–Up. . Cornell Policy Review. web log, . Retrieved 2019, from http://www.cornellpolicyreview.com/agricultural-technology-adoption-issues-for-consideration-when-scaling-up/?pdf=104

Place, F., & Swallow, B. (2000). Assessing the relationship between property rights and and Technology Adoption in Smallholder Agriculture: A Review of Issues and Empirical Methods. International Food Policy Research Institute . Retrieved 2019, from https://www.researchgate.net/publication/5057149_Assessing_the_Relationships_Between_Property_Rights_and_Technology_Adoption_in_Smallholder_Agriculture_A_Review_of_Issues_and_Empirical_Methods/link/00b7d5242ea83bbf2e000000/download

Rakotomalala, R. (2017). Interpreting the cluster analysis results. Université Lumière Lyon 2. Retrieved 2019, from http://eric.univ-lyon2.fr/~ricco/cours/slides/en/classif_interpretation.pdf

Rogers, E. M. (1995). Diffusion of Innovations (4th Eds.).University of Minnesotta Retrieved October 2019 from https://www.d.umn.edu/~lrochfor/ireland/dif–of–in–ch06.pdf

SAC, Colombian Farmers Association (2019). La SAC manifiesta preocupación por la reducción en el presupuesto del sector agropecuario para el 2020. Retrieved October 2019 from https://sac.org.co/la-sac-manifiesta-preocupacion-por-la-reduccion-en-el-presupuesto-del-sector-agropecuario-para-el-2020/

Romesburg, H. C. (2007). Cluster analysis for researchers. Raleigh, Utah: Lulu Press. Retrieved 2004, from https://digitalcommons.usu.edu/envs_facpub/42/

Romero, C. (2020, February 17). 262.197 muertos dejó el conflicto armado. Centro Nacional de Memoria Histórica. Retrieved October 11, 2019, from http://centrodememoriahistorica.gov.co/262-197-muertos-dejo-el-conflicto-armado/

Sajjad, H., & Nasreen, I. (2016). Assessing farm-level agricultural sustainability using site-specific indicators and sustainable livelihood security index: Evidence from Vaishali district, India. Community Development, 47(5), 602–619. Retrieved 2019, from https://www.researchgate.net/publication/306400365_Assessing_farm-level_agricultural_sustainability_using_site-specific_indicators_and_sustainable_livelihood_security_index_Evidence_from_Vaishali_district_India

Serrano, J. A. S. (1970). La desigualdad en el reparto de la tierra en Colombia: Obstáculo principal para una paz duradera y democrática. Anales de Geografía de la Universidad Complutense, 38(2), 409–433. Retrieved 2019, from http://dx.doi.org/10.5209/AGUC. 62486

Sunding, D., & Zilberman, D. (2001). Chapter 4 The agricultural innovation process: Research and technology adoption in a changing agricultural sector. Handbook of Agricultural Economics Agricultural Production, 207–261. Retrieved 2019, from https://www.sciencedirect.com/science/article/pii/S1574007201100071

Tadesse, M. (2014). Fertilizer adoption, credit access, and safety nets in rural Ethiopia. Agricultural Finance Review, 74(3), 290–310. Retrieved 2019, from https://www.researchgate.net/publication/265969054_Fertilizer_adoption_credit_access_and_safety_nets_in_rural_Ethiopia

Tan,, P.-N., Karpatne, A., & Kumar, V. (2019). Cluster analysis: Basic concepts and Algorithms. In M. Steinbach (Ed.), Introduction to Data Mining (pp. 1–88). essay, New York, New York: Pearson. Retrieved 2019, from https://www-users.cs.umn.edu/~kumar001/dmbook/index.php

Taher, S. (1996). Factors influencing smallholder cacao production. A management analysis of behavioral decision–making processes of technology adoption and application. (thesis). WUR Library. Retrieved 2019, from https://library.wur.nl/mwg-internal/de5fs23hu73ds/progress?id=aKOvxrVha5_i81unVYnDfQtH6JXR4n80p8GTvktGExE,&dl

Tibshirani, R., Walther, G., & Hastie, T. (2001). Estimating the number of clusters in a data set via the gap statistic. Journal of the Royal Statistical Society: Series B (Statistical Methodology), 63(2), 411–423. Retrieved 2019, from https://www.researchgate.net/publication/4772044_Estimating_the_Number_of_Clusters_in_a_Data_Set_Via_the_Gap_Statistic

Sebeko , T. (2015). Assessment of Postharvest loss for perishable produce from Wholesalers to consumers A case study of Et–fruit distribution company In Addis Ababa, Ethiopia. (thesis). Epsilon.slu.se. Swedish University of

Agricultural Science, Uppsala. Retrieved 2019, from https://stud.epsilon.slu.se/8445/1/Sebeko_T_150821.pdf

Torres Morantes, F. A., & Rodríguez Barrios, D. L. (2015). Análisis de la adopción de tecnología mejorada para la producción de cacao en el municipio de Rionegro - Santander. (thesis). RepositoryUSB. Universidad Santo Tomas , Bucaramanga. Retrieved 2019, from https://repository.usta.edu.co/bitstream/handle/11634/875/2015-TorresMorantesFelixAlberto-Tesis.pdf?sequence=1&isAllowed=y

University of California, L. A. (2006). PROBIT REGRESSION | STATA DATA ANALYSIS EXAMPLES. UCLA: Statistical Consulting Group. Retrieved 2019, from https://stats.idre.ucla.edu/stata/dae/probit-regression/

World Food Programme, U. N. (2017). Colombia Annual Country Report 2017. United Nation World Food Programme. Retrieved 2019, from https://docs.wfp.org/api/documents/WFP0000071512/download/?_ga=2.41502754.1403378363.1535468582%E2%80%931155816109.1535468582

Zeller, M., Diagne, A., & Mataya, C. (1998). Market access by smallholder farmers in Malawi: implications for technology adoption, agricultural productivity and crop income. Agricultural Economics, 19(1-2), 219–229. Retrieved 2019, from Market access by smallholder farmers in Malawi: implications for technology adoption, agricultural productivity and crop income

Zilberman, D., Khanna, M., & Lipper, L. (1997). Economics of new technologies for sustainable agriculture. The Australian Journal of Agricultural and Resource Economics, 41(1), 63–80. Retrieved 2019, from https://onlinelibrary.wiley.com/doi/pdf/10.1111/1467-8489.00004

# Appendix A:

Type of possible investments supported by FINAGRO (Free translation from the original document is Spanish made by the author of the thesis).

**INVESTMENT**

Plantation and maintenance: Financing of the direct costs for the establishment and its maintenance during the unproductive years, as well as the renewal of areas that finish their productive cycle or that are affected by adverse climatic situations or by the occurrence of phytosanitary problems of plant species of medium and late yield (vegetative cycles greater than two years), associated with soil preparation, acquisition of seeds or plant material, planting, fertilization, technical assistance, weed and phytosanitary control, irrigation supply and evacuation, road infrastructure, infrastructure of support, cover crops or shade, its support in the unproductive period and land lease when paid directly to the owner.

**Acquisition of machinery and equipment, and repair of machinery:** Acquisition of machinery and equipment, new or used, required in the production, collection and benefit processes at the level of the productive unit of agricultural activities; as well as its repair.

**Land adequacy:** Investment costs in activities whose purpose is to improve the conditions of production of agricultural goods, through the conditioning of the physical and chemical state of soils, the provision of irrigation systems, drainage and flood control, and adaptation to the management of water resources.

In the case of irrigation and drainage projects, water resource management and electrification, investments may be financed that, at an extra property level, are demanded to ensure the full operation of the respective system, including the purchase of land and the payment of easements .

**Infrastructure for agricultural production:** Investment costs for the provision of production infrastructure such as warehouses, greenhouses or rooms for production at controlled temperatures, worker camps, among others.

**Infrastructure and equipment for primary transformation and commercialization:** Infrastructure investment costs and provision of machinery and equipment (new or used) for the storage, primary transformation, conservation and commercialization of agricultural goods of national origin.

**Infrastructure for production support services:** Infrastructure investment costs and provision of machinery and equipment required (new or used) in projects aimed at providing support services for agricultural production and production and marketing of inputs and goods of capital for these.

Land, rural housing, capitalization and creation of companies, and research:

**Land purchase:** Investment costs in the purchase of land for use in the production of agricultural goods. In the follow–up to these credits, the financial intermediaries, in the 120 days following the accounting of the credit, must demand from the beneficiaries the presentation of the deed of the property object of financing and a certificate of freedom and recent tradition, in which record such a fact.

**Rural housing:** Investment costs for construction and improvement of housing, located in properties linked to agricultural production processes.

**Capitalization, purchase and creation of companies**: credit requested directly by natural or legal persons, for the constitution or increase of the capital stock of legal persons whose purpose is the development of agricultural, aquaculture, fishing and rural activities. The contributions must be based on the capital needs of the company for the execution of the productive process, either as working capital (operating costs) or as an investment, excluding the resources for cancellation of liabilities. The purchase of shares or participation quotas of incorporated companies is also eligible.

**Research:** Investment costs in infrastructure, provision of machinery and equipment, and in the realization of feasibility studies, in projects aimed at improving the technical conditions of agricultural production and marketing

Technical Assistance: the costs associated with the technical assistance service for the development of the crop.

Source: Self–made translation from a document from FINAGRO (2016).

# Appendix B. Questionnaire in Spanish

Encuesta de diagnóstico – Población Cacaocultora Sur del Tolima

Nombre del Encuestado:________________________________________ Edad_________

Coordenadas: N____________ E____________ Altitud__________msnm

Area________

Municipio__________ Vereda____________ pH___________

1. Cuál de los siguientes fenómenos ha causado daños en sus fincas:
   a. El Niño b. La Niña c. Ola invernal d. Otro_____________
2. Cuál de las siguientes prácticas de conservación de agua tiene implementada (s) en su finca?
   a. Reforestación in situ b. Reforestación Ex situ c. Revegetalización natural d. Siembra de pastos de amarre e. Siembra de barreras vivas f. Ninguna g. Otro_________
3. Considera usted que los problemas de acidez afectan la productividad de su finca? Si____ No____
4. Identifique los tipos de erosión que se pueden observar en su finca:
   a. Erosión eólica b. Erosión hídrica c. Erosión por pendiente d. Erosión antropogénica e. Ninguno
5. En los últimos 10 años, en cuáles ha notado usted cambios en los patrones de temperatura?
   a. 2006 b. 2007 c. 2008 d. 2009 e. 2010 f. 2011 g. 2012 h. 2013 i. 2014 j. 2015 k. 2016
6. En los último s 10 años, en cuáles ha notado usted cambios en los patrones y estacionalidad de las lluvias
   a. 2006 b. 2007 c. 2008 d. 2009 e. 2010 f. 2011 g. 2012 h. 2013 i. 2014 j. 2015 k. 2016
7. Explique brevemente qué entiende usted por cambio climático y cómo lo observa en su cotidianidad



8. Cuáles han sido los efectos del cambio climático sobre su productividad?
   a. Disminución b. Aumento c. Retraso d. Ninguno e. Otro _____________
9. Cuáles de las siguientes prácticas de adaptación al CC ha implementado usted en su finca?
   a. Sistema agroforestal b. Nuevos genotipos c. Sistemas de conservación de agua y suelo d. Ninguno e. Otro _________
10. Cuántas veces al año compra fertilizante? a. 1 b. 2 c. 3 d. 4 e. 5
11. Qué tipo de fertilizante compra? a. Simple N b. Simple P c. Simple K d. Binario e. Compuesto NPK f. Orgánico g. No compra
12. Cuántas veces al año aplica fertilizante? a. 1 b. 2 c. 3 d. 4 e. 5
13. Qué tipo de enmienda de pH aplican en su finca? a. Cal b. Cal dolomítica c. Fosforita d. Cal agrícola e. Dolomita con azufre f. Otro ___________ g. Ninguno
14. Cuántas veces al año hace encalamiento? a. 1 b. 2 c. 3 d. 4 e. 5
15. Describa brevemente las prácticas de fertilización que realiza en su plantación (Cantidad, periodicidad, métodos)

16. Describa brevemente como afecta la fluctuación de los precios la rentabilidad de su plantación y la toma de decisiones
17. Qué niveles de sombra tiene establecidos para áreas en etapa de producción? _________ %
18. Cuántas especies diferentes al cacao tiene sembradas en el área en etapa de producción? _________ #
19. Cuáles son las plantas que acompañan al cacao en el área en etapa de producción?
20. Qué beneficios presenta en su plantación la implementación de un sistema agroforestal multiestratificado?
a. Mejoramiento de las condiciones del suelo b. Conectividad ecológica c. Polinización por aves d. Menor incidencia de patógenos e. Aumento del flujo de caja de la finca f. Ninguno g. Otro _________
21. Cuántos genotipos de cacao tiene sembrados en el area en etapa de producción? __________ #
22. Cuáles de los siguientes genotipos están establecidos en el área en etapa de producción? a. ICS___ b. IMC___ c. CCN51 d. EET___ e. TSH___ f. FLE___ g. FTA___ h. FEAR___ i. FEC___ j. FSV__ k. CAU___ l. SCC___ m. FSA___ n. FGI___ o. FMA___ p. FYC___ q. Otro __________
23. Cuáles de los siguientes métodos de propagación fueron implementados para el establecimiento de la plantación? a. Siembra directa (semilla) b. Trasplante de plántula c. Injertación
24. Cómo califica usted la respuesta de los genotipos a las condiciones agroclimáticas de la finca?
a. Baja b. Media c. Buena d. Excelente
25. Implementa usted un modelo productivo de autocompatibilidad, calidad y rendimiento según las recomendaciones de FEDECACAO? Sí_____ No_____
26. Cuáles de los siguientes tipos de poda realiza en su plantación? a. Formación b. Mantenim c. Sanitaria
27. Cómo califica usted el servicio de asistencia técnica agrícola en su finca? a. Ausente

28. Cuál es la densidad de plantas de Cacao en su plantación? _________ árboles por ha
29. Cuál es su experticia en el manejo de plantaciones de Cacao? a. Principiante b. En capacitación c. Capacitado d. Productor experto
30. Con cuáles de las siguientes herramientas cuenta usted en la finca? a. Motosierra b. Machete c. Tijeras para podar d. Guantes e. Pasta cicatrizante f. Cinta plástica para marcar g. Ninguna
31. Cuál es la situación legal del predio en el que está establecida su plantación? a. Propietario b. Poseedor legal c. Arrendatario d. Ocupante de bien baldío e. Invasor f. Otro_________
32. Suple los costos de su sistema productivo a través de crédito agrario? Sí_____ No_____
33. Otras obligaciones financieras a. Cooperativa b. Crédito convencional c. T crédito d. Chequera e. Otro
34. Describa brevemente las fuentes de ingreso que sustentan la economía familiar de su unidad productiva
35. Es su conyugue activa(o) en el sistema productivo familiar? Sí______ No______
36. Número de hijos habilitados para trabajar y activos en la finca _________ #
37. Número de hijos que han migrado de la zona para dedicarse a otras actividades _________ #
38. Recibe algún dinero de miembros de la familia que han emigrado a otras zonas? Sí______ No ______

39. Cuál es la procedencia de la mano de obra que trabaja en su finca? a. Grupo familiar b. Trabajadores de la zona c. Trabajadores de otra zona d. Único trabajador e. Otro__________
40. Describa brevemente el proceso de consecución de mano de obra para el trabajo de la finca
41. Cuáles de los siguientes tipos de trabajadores se pueden conseguir fácilmente en la zona? a. Podadores b. Jornaleros c. Injertadores d. Agrónomo
42. Cuál es el rango de edad promedio de los trabajadores disponibles? a. 15 – 30 b. 30 – 45 c. 45 -60 d. Mayores de 60
43. En cuál (es) de las siguientes modalidades de producción se clasifica? a. Alianza productiva con apoyo financiero del ministerio b. Asociación de productores independiente c. Asociación de mujeres campesinas d. Socio en cooperativa e. Productor independiente
44. Describa brevemente el proceso de adquisición de insumos para la plantación
45. Cuál es la distancia entre su plantación y el almacen en el que se aprovisiona de insumos? ______ Km
46. Describa brevemente el proceso de comercialización de su producto beneficiado
47. Cuál es la distancia entre su plantación y la agencia que compra su producto beneficiado _______Km
48. A quién vende usted su producto beneficiado? a. Cooperativa (precio regulado ) b. Agencia independiente (precio no regulado) c. Venta directa a cliente externo d. Venta a vecino e. Otro__________
49. Es un hombre o una mujer quien está al mando de su unidad productiva? Mujer ______ Hombre_____
50. Pertenece usted a alguna de las siguientes categorías de víctimas del conflicto armado colombiano? a. Abandono o despojo forzado, b. Acto terrorista/atentado/combate/hostigamiento c. Amenaza d. Afección a la libertad o integridad sexual e. Desaparición forzada f. Desplazamiento g. Homicidio h. mina antipersonal/munición sin explotar/artefacto explosivo i. pérdida de bienes muebles o inmuebles j. Secuestro k. Torturado l. vinculación al conflicto como



mina antipersonal/munición sin explotar/artefacto explosivo i. pérdida de bienes muebles o inmuebles j. Secuestro k. Torturado l. vinculación al conflicto como
menor de edad m. no víctima
51. Cuál ha sido el rendimiento de su plantación en los últimos cinco años? a. 2012__________ ton/ha b. 2013 _______ton/ha c. 2014 _______ ton/ha d. 2015 _______ ton/ha e. 2016 _________ ton/ha
52. Cómo se clasifica su producción dentro de las categorías establecidas por el ministerio de agricultura? a. Pequeño productor b. joven rural c. mujer rural d. mediano productor e. Gran productor f. Productor asociativo g. Productor integrado
53. Qué tipo de sistema sanitario tiene instalado en su finca? a. Letrina b. Inodoro conectado a red de alcantarillado municipal c. Inodoro conectado a pozo séptico d. Biodigestor e. Ninguno f. Otro___________
54. A qué tipo de sistema de seguridad social están inscritos los miembros de la familia? a. Seguro estatal b. Seguro de la cooperativa c. Seguro privado d. Ninguno e. Otro__________
55. Enfermedades observadas en la plantación: ______________________________________________________________________
________________

# Appendix C: Results from Cluster Analysis (until 3 clusters)

```
> ClusterData[which(gower_mat == min(gower_mat[gower_mat != min(gower_mat)]),
arr.ind = TRUE)[1, ], ]
   Farm.number SS_FoodSec SS_offspAct TA_frExprts_1
36  -0.7127841  0.7429269   -0.597793     0.9093113
28  -0.9408751  0.7429269   -0.597793     0.9093113
   TA_loclWrks_1 TA_areaPlan TA_sewageS_1 TA_frMachet_1
36     -1.317398  -0.5737550    0.6800351    0.09090909
28     -1.317398  -0.7672453    0.6800351    0.09090909
   TA_frSccisr_1 TA_frGloves_1 TA_frHealP_1 TA_frPlastT_1
36     0.2989072    -0.5209821   -0.5844637    -0.3149183
28     0.2989072    -0.5209821   -0.5844637    -0.3149183
   TA_ToolsUse ES_finSuppt_1 ES_extSrvc_1 ES_spsActv_1
36  -0.4916888    -0.4163088   -0.2706184    0.7527988
28  -0.4916888    -0.4163088   -0.2706184    0.7527988
   prunForm_1 prunMant_1 prunSant_1   noPrun_1
36  0.4298082  0.4026296  0.4026296 -0.3602219
28  0.4298082  0.4026296  0.4026296 -0.3602219
   mmbrs_clus_1
36    0.3746197
28    0.3746197
>
> #Comparing dif set of clusters
> k3 <- kmeans(ClusterData, centers = 3, nstart = 25)
> k3
K-means clustering with 3 clusters of sizes 22, 15, 84

Cluster means:
  Farm.number SS_FoodSec SS_offspAct TA_frExprts_1
1  0.11663741  0.2141377  0.32280820    -1.2456826
2  0.22999168 -0.1031357 -0.11557331     0.3725959
3 -0.07161784 -0.0376666 -0.06390691     0.2597152
  TA_loclWrks_1 TA_areaPlan TA_sewageS_1 TA_frMachet_1
1    0.18819970   0.3673119   0.08019282    0.09090909
2   -0.07527988  -0.1867742   0.11077301    0.09090909
3   -0.03584756  -0.0628482  -0.04078378   -0.04004329
  TA_frSccisr_1 TA_frGloves_1 TA_frHealP_1 TA_frPlastT_1
1    0.29890725     1.3525497   1.07465903     1.1022142
2   -0.90668532     0.2872081   0.02388131     0.1469619
3    0.08362286    -0.4055264  -0.28572284    -0.3149183
  TA_ToolsUse ES_finSuppt_1 ES_extSrvc_1 ES_spsActv_1
1  1.50094471    0.21971853    0.6507728   0.09409985
2 -0.07418462    0.14339525   -0.1666666   0.06273323
3 -0.37985731   -0.08315162   -0.1406786  -0.03584756
  prunForm_1 prunMant_1 prunSant_1   noPrun_1
```

```
1   0.305390  0.1421046  0.2723671 -0.3602219
2  -2.307391 -2.2720942 -2.4631460  2.5455678
3   0.332051  0.3685133  0.3685133 -0.3602219
  mmbrs_clus_1
1  -0.03746197
2  -0.22976676
3   0.05084125

Clustering vector:
  1   2   3   4   5   6   7   8   9  10  11  12  13  14
  1   3   1   3   3   3   3   3   1   3   3   1   3   1
 15  16  17  18  19  20  21  22  23  24  25  26  27  28
  3   3   3   3   3   3   3   3   3   3   3   3   3   3
 29  30  31  32  33  34  35  36  37  38  39  40  41  42
  3   3   3   3   3   3   3   3   1   3   3   1   2   2
 43  44  45  46  47  48  49  50  51  52  53  54  55  56
  1   1   2   3   3   2   3   3   3   2   1   3   2   3
 57  58  59  60  61  62  63  64  65  66  67  68  69  70
  3   3   3   3   3   1   2   3   3   1   3   3   3   2
 71  72  73  74  75  76  77  78  79  80  81  82  83  84
  2   3   3   3   3   3   1   3   3   3   2   3   2   3
 85  86  87  88  89  90  91  92  93  94  95  96  97  98
  1   3   2   2   2   3   3   3   1   3   3   3   3   3
 99 100 101 102 103 104 105 106 107 108 109 110 111 112
  3   3   3   3   3   1   3   3   1   3   3   3   3   3
113 114 115 116 117 118 119 120 121
  1   3   1   1   3   1   3   1   2

Within cluster sum of squares by cluster:
[1]  433.8461  279.6612 1143.4449
 (between_SS / total_SS =  26.3 %)

Available components:

[1] "cluster"      "centers"      "totss"
[4] "withinss"     "tot.withinss" "betweenss"
[7] "size"         "iter"         "ifault"
#Computing optimal number of clusters
> #ElbowMethod
> set.seed(123)
> fviz_nbclust(ClusterData, kmeans, method = "wss")
>
> #Sombra
> fviz_nbclust(ClusterData, kmeans, method = "silhouette")
> sil_width <- c(NA)
> for(i in 2:8){
+   pam_fit <- pam(gower_dist, diss = TRUE, k = i)
+   sil_width[i] <- pam_fit$silinfo$avg.width}
> plot(1:8, sil_width, xlab = "Number of clusters", ylab = "Silhouette Width")
> lines(1:8, sil_width)
>
```

```
> #GAPMethod
>
> set.seed(123)
> gap_stat <- clusGap(ClusterData, FUN = kmeans, nstart = 25,K.max = 8, B = 50)
Clustering k = 1,2,..., K.max (= 8): .. done
Bootstrapping, b = 1,2,..., B (= 50)  [one "." per sample]:
.................................................. 50
>
> # Print the result
> print(gap_stat, method = "firstmax")
Clustering Gap statistic ["clusGap"] from call:
clusGap(x = ClusterData, FUNcluster = kmeans, K.max = 8, B = 50,     nstart = 25)
B=50 simulated reference sets, k = 1..8; spaceH0="scaledPCA"
 --> Number of clusters (method 'firstmax'): 8
         logW   E.logW       gap     SE.sim
[1,] 5.217862 5.727596 0.5097341 0.01249754
[2,] 5.120696 5.648105 0.5274087 0.01077430
[3,] 5.055567 5.594312 0.5387456 0.01105109
[4,] 5.007950 5.556781 0.5488309 0.01130318
[5,] 4.970619 5.529075 0.5584559 0.01133506
[6,] 4.930422 5.504109 0.5736866 0.01114125
[7,] 4.898450 5.481133 0.5826826 0.01146228
[8,] 4.858401 5.459654 0.6012521 0.01154022
>
> #GAPMethodGraph
> fviz_gap_stat(gap_stat)
>
> # Compute k-means clustering with k = 2
> set.seed(123)
> final <- kmeans(ClusterData,2, nstart = 25)
> print(final)
K-means clustering with 2 clusters of sizes 18, 103

Cluster means:
  Farm.number  SS_FoodSec SS_offspAct TA_frExprts_1
1  0.12830115  0.09662905 -0.19594325    0.16387318
2 -0.02242156 -0.01688663  0.03424251   -0.02863803
  TA_loclWrks_1 TA_areaPlan TA_sewageS_1 TA_frMachet_1
1  -0.052277694  0.41519589   0.07627228    0.09090909
2   0.009135908 -0.07255851  -0.01332914   -0.01588703
  TA_frSccisr_1 TA_frGloves_1 TA_frHealP_1 TA_frPlastT_1
1    -0.7057532    0.42190645   0.04922902    0.26243194
2     0.1233355   -0.07373122  -0.00860313   -0.04586189
  TA_ToolsUse ES_finSuppt_1 ES_extSrvc_1 ES_spsActv_1
1  0.08817811   0.050111243 -0.010738826   0.17774416
2 -0.01540977  -0.008757305  0.001876688  -0.03106209
  prunForm_1 prunMant_1 prunSant_1   noPrun_1
1 -2.1553245 -2.3039362 -2.1447264  2.0612695
2  0.3766587  0.4026296  0.3748066 -0.3602219
  mmbrs_clus_1
1   -0.6326911
```

```
2    0.1105674

Clustering vector:
  1   2   3   4   5   6   7   8   9  10  11  12  13  14 
  2   2   2   2   2   2   2   2   2   2   2   2   2   2 
 15  16  17  18  19  20  21  22  23  24  25  26  27  28 
  1   2   2   2   2   2   2   2   2   2   2   2   2   2 
 29  30  31  32  33  34  35  36  37  38  39  40  41  42 
  2   2   2   2   2   2   2   2   2   2   2   2   1   1 
 43  44  45  46  47  48  49  50  51  52  53  54  55  56 
  2   2   1   2   2   1   2   2   2   1   2   2   1   2 
 57  58  59  60  61  62  63  64  65  66  67  68  69  70 
  2   2   2   2   2   1   1   2   2   1   2   2   2   1 
 71  72  73  74  75  76  77  78  79  80  81  82  83  84 
  1   2   2   2   2   2   2   2   2   2   1   2   1   2 
 85  86  87  88  89  90  91  92  93  94  95  96  97  98 
  2   2   1   1   1   2   2   2   2   2   2   2   2   2 
 99 100 101 102 103 104 105 106 107 108 109 110 111 112 
  2   2   2   2   2   2   2   2   2   2   2   2   2   2 
113 114 115 116 117 118 119 120 121 
  2   2   2   2   2   2   2   2   1 

Within cluster sum of squares by cluster:
[1]  438.5837 1652.7488
 (between_SS / total_SS =  17.0 %)

Available components:

[1] "cluster"      "centers"      "totss"       
[4] "withinss"     "tot.withinss" "betweenss"   
[7] "size"         "iter"         "ifault"      
> 
> #Visualize Results
> fviz_cluster(final, data = ClusterData)
> 
> #H Clustering
> dist_mat <- dist(ClusterData, method = 'euclidean')
> 
> hclust_avg <- hclust(dist_mat, method = 'average')
> plot(hclust_avg)
> 
> #clustermembersh  created and included in mtds
```

# Appendix D: Logit regression analysis results

```
#Log regression Analysis
> 
> #A  Tech. Addoption factors explained by management pract
> TAEC1 <- 
glm(mmbrs_clus_1~DV_agCredt_1+SS_frGender_1+TA_ldTenure_1+TA_areaPlan, data = 
mtds)
```

```
> summary(TAEC1)

Call:
glm(formula = mmbrs_clus_1 ~ DV_agCredt_1 + SS_frGender_1 + TA_ldTenure_1 +
    TA_areaPlan, data = mtds)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.62720  -0.04699   0.05113   0.12377   0.45550

Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)    2.124360   0.114294  18.587   <2e-16 ***
DV_agCredt_1  -0.022200   0.040515  -0.548    0.585
SS_frGender_1  0.003161   0.053075   0.060    0.953
TA_ldTenure_1  0.030994   0.026400   1.174    0.243
TA_areaPlan   -0.100876   0.007206 -13.999   <2e-16 ***
---
Signif. codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.04084734)

    Null deviance: 13.1405  on 120  degrees of freedom
Residual deviance:  4.7383  on 116  degrees of freedom
AIC: -36.671

Number of Fisher Scoring iterations: 2

>
> TAEC2 <-
glm(mmbrs_clus_1~DV_agCredt_1+SS_frGender_1+TA_ldTenure_1+TA_areaPlan+ES_sps
Actv_1+ES_famLabor+TA_loclWrks_1, data = mtds)
> summary(TAEC2)

Call:
glm(formula = mmbrs_clus_1 ~ DV_agCredt_1 + SS_frGender_1 + TA_ldTenure_1 +
    TA_areaPlan + ES_spsActv_1 + ES_famLabor + TA_loclWrks_1,
    data = mtds)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.58765  -0.06174   0.02608   0.11024   0.45148

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    2.03208    0.11725  17.331   <2e-16 ***
DV_agCredt_1  -0.03710    0.04063  -0.913   0.3631
SS_frGender_1  0.01562    0.05322   0.293   0.7697
TA_ldTenure_1  0.01968    0.02645   0.744   0.4585
TA_areaPlan   -0.10344    0.00731 -14.150   <2e-16 ***
```

```
ES_spsActv_1   0.02544    0.04385   0.580   0.5630
ES_famLabor    0.04311    0.02439   1.768   0.0798 .
TA_loclWrks_1  0.02456    0.04332   0.567   0.5720
---
Signif. codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.03933482)

    Null deviance: 13.1405  on 120  degrees of freedom
Residual deviance:  4.4448  on 113  degrees of freedom
AIC: -38.407

Number of Fisher Scoring iterations: 2

>
> TAEC3 <-
glm(mmbrs_clus_1~DV_agCredt_1+SS_frGender_1+TA_ldTenure_1+TA_areaPlan+ES_sps
Actv_1+ES_famLabor+TA_loclWrks_1+altitude+ES_dsAgency+ES_prodType_1+TA_frExp
rts_1+ES_extSrvc_1+ES_prefByer_1+EnS_orgnAppl_1+TA_sewageS_1+TA_ToolsUse+ES
_dsAgency+ES_y2015+SS_cnflcVic_1, data = mtds)
> summary(TAEC3)

Call:
glm(formula = mmbrs_clus_1 ~ DV_agCredt_1 + SS_frGender_1 + TA_ldTenure_1 +
    TA_areaPlan + ES_spsActv_1 + ES_famLabor + TA_loclWrks_1 +
    altitude + ES_dsAgency + ES_prodType_1 + TA_frExprts_1 +
    ES_extSrvc_1 + ES_prefByer_1 + EnS_orgnAppl_1 + TA_sewageS_1 +
    TA_ToolsUse + ES_dsAgency + ES_y2015 + SS_cnflcVic_1, data = mtds)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.57927  -0.05597   0.03771   0.11010   0.39838

Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)     1.7401434  0.2861229   6.082  2.3e-08 ***
DV_agCredt_1   -0.0509097  0.0470453  -1.082    0.282
SS_frGender_1  -0.0030672  0.0640366  -0.048    0.962
TA_ldTenure_1   0.0279001  0.0294443   0.948    0.346
TA_areaPlan    -0.1061805  0.0088618 -11.982  < 2e-16 ***
ES_spsActv_1    0.0188586  0.0468753   0.402    0.688
ES_famLabor     0.0428413  0.0265375   1.614    0.110
TA_loclWrks_1   0.0041338  0.0483162   0.086    0.932
altitude        0.0002122  0.0001830   1.160    0.249
ES_dsAgency    -0.0012974  0.0026743  -0.485    0.629
ES_prodType_1   0.0469059  0.0897488   0.523    0.602
TA_frExprts_1  -0.0102815  0.0199016  -0.517    0.607
ES_extSrvc_1    0.0460908  0.0357367   1.290    0.200
ES_prefByer_1   0.0136419  0.0595353   0.229    0.819
EnS_orgnAppl_1 -0.0020313  0.1174394  -0.017    0.986
```

```
TA_sewageS_1   -0.0246823  0.0156756  -1.575    0.119
TA_ToolsUse     0.0206645  0.0244265   0.846    0.400
ES_y2015       -0.0315939  0.0364463  -0.867    0.388
SS_cnflcVic_1   0.0133703  0.0185007   0.723    0.472
---
Signif. codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.04146116)

    Null deviance: 13.0769  on 116  degrees of freedom
Residual deviance:  4.0632  on  98  degrees of freedom
  (4 observations deleted due to missingness)
AIC: -21.112

Number of Fisher Scoring iterations: 2

> TAECUni <- glm(mmbrs_clus_1~SS_cnflcVic_1, data = mtds)
> summary(TAECUni)

Call:
glm(formula = mmbrs_clus_1 ~ SS_cnflcVic_1, data = mtds)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.92774   0.07226   0.11966   0.16706   0.21446

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    1.73813    0.08606  20.197   <2e-16 ***
SS_cnflcVic_1  0.04740    0.02775   1.708   0.0902 .
---
Signif. codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.1077808)

    Null deviance: 13.140  on 120  degrees of freedom
Residual deviance: 12.826  on 119  degrees of freedom
AIC: 77.82

Number of Fisher Scoring iterations: 2

> #Robustness tests
> install.packages("Rcpp")
Error in install.packages : Updating loaded packages
> install.packages("dplyr")
Error in install.packages : Updating loaded packages
>
> TAEC4<-glm (mmbrs_clus_1~DV_agCredt_1+SS_frGender_1, data = mtds)
> summary(TAEC4)
```

```
Call:
glm(formula = mmbrs_clus_1 ~ DV_agCredt_1 + SS_frGender_1, data = mtds)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.8990   0.1010   0.1367   0.1367   0.1367

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    1.892613   0.113282  16.707   <2e-16 ***
DV_agCredt_1  -0.035711   0.064415  -0.554    0.580
SS_frGender_1  0.006424   0.087200   0.074    0.941
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.1110642)

    Null deviance: 13.140  on 120  degrees of freedom
Residual deviance: 13.106  on 118  degrees of freedom
AIC: 82.43

Number of Fisher Scoring iterations: 2

>
> #1 change in set of regressors
> TAEC5 <-
glm(mmbrs_clus_1~ES_incomeSr_1+ES_extIncom_1+ES_y2015+ES_prodType_1+ES_fam
Labor+TA_loclWrks_1+ES_cattle_1+ES_frVegOrc_1+ES_fdWkr_1+ES_finSuppt_1+ES_ex
tSrvc_1+ES_frType_1+ES_spsActv_1+ES_prefByer_1+ES_dsAgency, data = mtds)
> summary(TAEC4)

Call:
glm(formula = mmbrs_clus_1 ~ DV_agCredt_1 + SS_frGender_1, data = mtds)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.8990   0.1010   0.1367   0.1367   0.1367

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    1.892613   0.113282  16.707   <2e-16 ***
DV_agCredt_1  -0.035711   0.064415  -0.554    0.580
SS_frGender_1  0.006424   0.087200   0.074    0.941
---
Signif. codes:
0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.1110642)
```

```
    Null deviance: 13.140  on 120  degrees of freedom
Residual deviance: 13.106  on 118  degrees of freedom
AIC: 82.43

Number of Fisher Scoring iterations: 2

>
> #4change in sample (adding or subtracting cases)
> mtds2 <-read.csv("C:/Users/PC-PERSONAL/Desktop/R/Inputs/cacao_1.0.csv", header =
TRUE)
> TAEC6 <-
glm(mmbrs_clus_1~DV_agCredt_1+SS_frGender_1+TA_ldTenure_1+ES_spsActv_1+ES_fa
mLabor+TA_loclWrks_1+ES_prodType_1+TA_frExprts_1+ES_extSrvc_1+ES_prefByer_1+
EnS_orgnAppl_1+TA_sewageS_1+TA_ToolsUse, data = mtds2)
> summary(TAEC6)

Call:
glm(formula = mmbrs_clus_1 ~ DV_agCredt_1 + SS_frGender_1 + TA_ldTenure_1 +
    ES_spsActv_1 + ES_famLabor + TA_loclWrks_1 + ES_prodType_1 +
    TA_frExprts_1 + ES_extSrvc_1 + ES_prefByer_1 + EnS_orgnAppl_1 +
    TA_sewageS_1 + TA_ToolsUse, data = mtds2)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.95861   0.01105   0.09736   0.16560   0.26844

Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)     2.265481   0.598608   3.785 0.000436 ***
DV_agCredt_1   -0.141227   0.132572  -1.065 0.292189
SS_frGender_1  -0.056335   0.139133  -0.405 0.687389
TA_ldTenure_1  -0.012016   0.099606  -0.121 0.904492
ES_spsActv_1    0.058542   0.111979   0.523 0.603572
ES_famLabor    -0.010408   0.068322  -0.152 0.879571
TA_loclWrks_1   0.030554   0.126414   0.242 0.810065
ES_prodType_1  -0.078574   0.209219  -0.376 0.708936
TA_frExprts_1   0.007067   0.049123   0.144 0.886218
ES_extSrvc_1   -0.027360   0.086783  -0.315 0.753956
ES_prefByer_1  -0.104211   0.152666  -0.683 0.498203
EnS_orgnAppl_1  0.004301   0.226816   0.019 0.984953
TA_sewageS_1   -0.004441   0.038988  -0.114 0.909790
TA_ToolsUse     0.042944   0.051666   0.831 0.410072
---
Signif. codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.1192474)

    Null deviance: 6.1967  on 60  degrees of freedom
Residual deviance: 5.6046  on 47  degrees of freedom
AIC: 57.486
```

```
Number of Fisher Scoring iterations: 2

>
> #5 Regressing Dependent variable againts one variable or set of variables representing
Labor intensiveness
> TAEC7<-glm(mmbrs_clus_1~TA_loclWrks_1+ES_spsActv_1+ES_famLabor, data =
mtds2)
> summary(TAEC7)

Call:
glm(formula = mmbrs_clus_1 ~ TA_loclWrks_1 + ES_spsActv_1 + ES_famLabor,
    data = mtds2)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.90684   0.09316   0.11922   0.12037   0.14643

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    1.85931    0.11272  16.495   <2e-16 ***
TA_loclWrks_1  0.03295    0.10854   0.304    0.763
ES_spsActv_1   0.03180    0.10215   0.311    0.757
ES_famLabor   -0.00574    0.05691  -0.101    0.920
---
Signif. codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.1083609)

    Null deviance: 6.1967  on 60  degrees of freedom
Residual deviance: 6.1766  on 57  degrees of freedom
AIC: 43.414

Number of Fisher Scoring iterations: 2

>
> #6 Regressing Dependent variable againts one variable or set of variables representing
Labor intensiveness
> TAEC8 <-
glm(mmbrs_clus_1~DV_agCredt_1+TA_ldTenure_1+ES_prodType_1+EnS_orgnAppl_1+T
A_sewageS_1+TA_ToolsUse+EnS_PestUse_1, data = mtds)
> summary(TAEC8)

Call:
glm(formula = mmbrs_clus_1 ~ DV_agCredt_1 + TA_ldTenure_1 + ES_prodType_1 +
    EnS_orgnAppl_1 + TA_sewageS_1 + TA_ToolsUse + EnS_PestUse_1,
    data = mtds)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
```

```
-0.9442   0.0314   0.1031   0.1264   0.4616

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)      2.32423    0.41540   5.595 1.56e-07 ***
DV_agCredt_1    -0.04379    0.06853  -0.639  0.52415
TA_ldTenure_1    0.05086    0.04288   1.186  0.23806
ES_prodType_1   -0.33451    0.11521  -2.903  0.00444 **
EnS_orgnAppl_1  -0.15501    0.16853  -0.920  0.35963
TA_sewageS_1    -0.02402    0.02327  -1.033  0.30400
TA_ToolsUse     -0.02366    0.03286  -0.720  0.47307
EnS_PestUse_1   -0.13347    0.34021  -0.392  0.69557
---
Signif. codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.1031148)

    Null deviance: 13.140  on 120  degrees of freedom
Residual deviance: 11.652  on 113  degrees of freedom
AIC: 78.205
```