MESTRADO EM

DESENVOLVIMENTO E COOPERAÇÃO INTERNACIONAL

TRABALHO FINAL DE MESTRADO

DISSERTAÇÃO

THE ROLE OF ICTS IN PROCESSING AGRICULTURAL DATA IN NORTH AND CENTRAL AMERICA AND THE CARIBBEAN:

PROSPECTS FOR FOOD SECURITY AND RURAL DEVELOPMENT

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“The livelihoods of the world's poor rise and fall with the fate of agriculture.”

- World Bank (2011)

RESUMO

O presente estudo tem por objetivo analisar o papel das tecnologias de informação e comunicação (TICs) no processamento de dados agrícolas em países selecionados da América do Norte, América Central e Caribe. Esta análise foi baseada numa revisão da literatura existente, sistemas nacionais e regionais de informação agrícola e 13 entrevistas com agências agrícolas nacionais na região responsáveis pelo processamento de dados agrícolas. A análise indica que algumas TICs específicas, nomeadamente smartphones, plataformas online como sistemas de informação agrícola e redes sociais, bem como tecnologias de observação da Terra, já trouxeram vários benefícios tangíveis para partes da região e sugere que o resto da região poderia beneficiar igualmente a partir da sua implementação.

Palavras-chave: agricultura, dados, tecnologia da informação e comunicação, segurança alimentar, desenvolvimento rural

ABSTRACT

The present study analyzes the role of information and communication technologies (ICTs) in processing agricultural data in select countries in North and Central American and the Caribbean. This analysis was based on a review of the existing literature, national and regional agricultural information systems, and 13 interviews with national-level agricultural agencies in the region responsible for processing agricultural data. The analysis indicates that specific ICTs, namely smartphones, online platforms such as agricultural information systems and social media, as well as earth observation technologies, have already brought several tangible benefits to parts of the region and suggests that the rest of the region could equally benefit from their implementation.

Keywords: agriculture, data, information and communication technology, food security, rural development

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ACRONYMS

ASI	Agricultural Statistics Institution
BAIMS	Belize Agriculture Information System
BANGUAT	*Banco de Guatemala*
EO	Earth Observation
ECLAC	Economic Commission for Latin America and the Caribbean (United Nations)
FAO	Food and Agriculture Organization
FHIA	*Fundación Hondureña de Investigación Agrícola*
GIS	Geographic Information System
ICT	Information and Communication Technology
IFAD	The International Fund for Agricultural Development
IMA	*Instituto de Mercado Agropecuario* (Panama)
INE	*Instituto Nacional de Estadísticas* (Guatemala)
INEGI	*Instituto Nacional de Estadística y Geografía* (Mexico)
ITU	International Telecommunication Union
MA	*Ministerio de Agricultura* (Dominican Republic)
MAFSEGB	Ministry of Agriculture, Food Security, and Enterprise of the Government of Belize
MAGA-DIPLAN	*Ministerio de Agricultura, Ganadería y Alimentación – División de Planeamiento* (Guatemala)
MAG-DGEA	*Ministerio de Agricultura y Ganadería – Dirección General de Economía Agropecuaria* (El Salvador)
MIDA	*Ministerio de Desarrollo Agropecuario* (Panama)
ONEI	*Oficina Nacional de Estadística e Información* (Cuba)
SDG	Sustainable Development Goal
SEPSA	*Secretaría Ejecutiva de Planificación Sectorial Agropecuaria* (Costa Rica)
SIAP	*Servicio de Información Agroalimentaria y Pesquera* (Mexico)
SICA	Central American Integration System

SIDIAGRO	*Sistema Digital de Información Agropecuaria* (Dominican Republic)
SIGAP	*Sistema Integrado de Gestión Agropecuaria de Panamá*
SIMMAGRO	*Sistema Regional de Inteligencia y Monitoreo de Mercados Agrícolas*
SIMPAH	*Sistema de Información de Mercados de Agricultura y Ganadería* (Honduras)
USDA-NASS	United States Department of Agriculture – National Agricultural Statistics Service
WFP	World Food Programme

1. INTRODUCTION

The agricultural sector holds great promise for inclusive social and economic development. The sector accounts for the vast majority of the poor's subsistence activities and it follows that agriculture is about four times more effective in raising incomes among the poor than other sectors (FAO and International Telecommunication Union (ITU) 2016). Additionally, improvements in agriculture have a direct impact on hunger and malnutrition, decreasing the occurrences of hunger, childhood stunting, and maternal diseases (World Bank 2011). In fact, as pointed out by ECLAC (2016) and shown in Table 1 below, agriculture and rural development have a direct impact on 12 of the 17 Sustainable Development Goals (SDGs) and still have an indirect impact on the remaining 5 SDGs, a collection of 17 goals designed by the United Nations deemed as crucial to promoting sustainable development now and into the future. Effectively raising the productivity and incomes of small producers in the agricultural sector is, therefore, a fundamental step not only to address global poverty but also to guarantee a future of peace and prosperity for all.

TABLE 1

LINKS BETWEEN AGRICULTURE AND RURAL DEVELOPMENT AND THE SDGS

Number	**Sustainable Development Goal**	**Link with agriculture and rural development**
1	End poverty in all its forms everywhere.	Yes
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture.	Yes

3	Ensure healthy lives and promote well-being for all at all ages.	Yes
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.	Yes
5	Achieve gender equality and empower all women and girls.	Yes
6	Ensure availability and sustainable management of water and sanitation for all.	Yes
7	Ensure access to affordable, reliable, sustainable and modern energy for all.	Indirectly
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.	Yes
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Indirectly
10	Reduce inequality within and among countries.	Yes
11	Make cities and human settlements inclusive, safe, resilient and sustainable.	Indirectly
12	Ensure sustainable consumption and production patterns.	Yes
13	Take urgent action to combat climate change and its impacts.	Yes
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.	Yes
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.	Yes
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.	Indirectly
17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development.	Indirectly

Source: ECLAC (2016), p.57

With the rise of food prices in recent years and farmers in developing countries struggling to keep up the pace, more effective interventions are essential in agriculture (FAO 2022a). The growing global population, which is expected to reach 9 billion by 2050, has increased demand for food and put pressure on already fragile resources. Feeding this population will require a significant increase in food production – a 70% increase as of 2011 (World Bank 2011).

Making the situation even more difficult, the agricultural sector is faced with many significant challenges – the negative impact of climate change, the increase in the frequency of natural disasters, drought, desertification, the loss of biodiversity, the increase in food and crude oil prices, the rapid expansion of bioenergy development, the increase in food price volatility, the inefficiency of supply chains, among others (FAO 2015).

These challenges are particularly felt in Central America and the Caribbean, two regions that I focus on in this paper. An area particularly vulnerable in the Central American region is the so-called Dry Corridor, a strip of territory that crosses Costa Rica, Nicaragua, Honduras, El Salvador, and Guatemala as seen in Figure 1. More than 10 million people live in this area, many of whom are engaged in agricultural activities, especially in the small production of basic grains (FAO 2022b).

The Central American Dry Corridor is an area highly vulnerable to extreme weather events, where long periods of drought are followed by intense rains that strongly affect the livelihoods and food security of local populations. According to FAO (2022), 80% of small producers here live in poverty, and many people are forced to migrate.

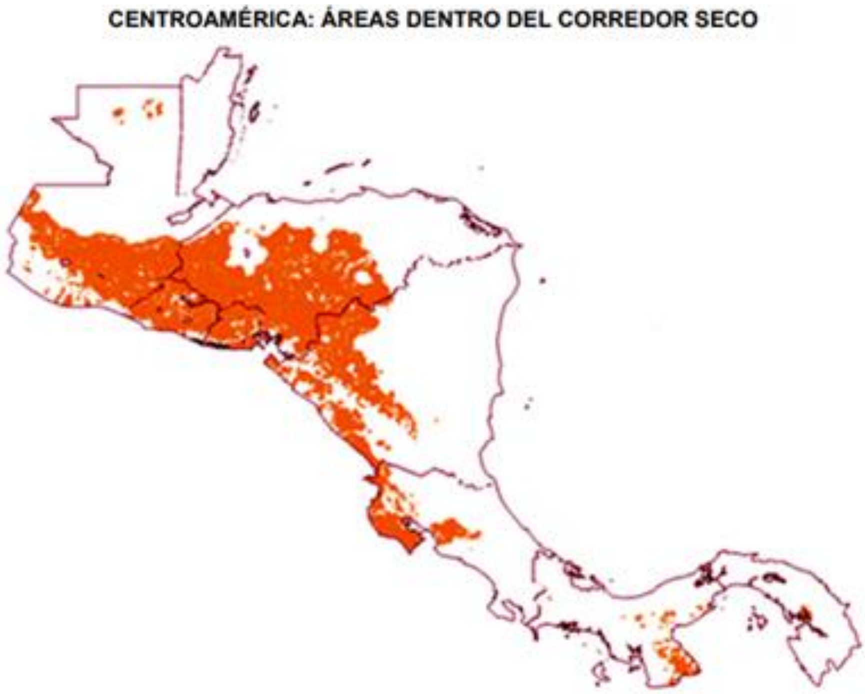

Figure 1 – The Central American Dry Corridor. Source: ECLAC (2016), p. 49

The Caribbean faces equally difficult challenges – a region that, like Central America, depends heavily on international trade and is particularly susceptible to climate change. Projections show that through the end of the century, the Caribbean is expected to see an increase in temperatures, rising sea levels, temporal and spatial changes in precipitation patterns, and more intense extreme weather events such as hurricanes (Taylor 2012). Arable land and water resources are already under pressure and agricultural lands are increasingly susceptible to inundation. Such effects not only threaten local food security, but also threaten revenue generated from export crops.

With these challenges in mind, it is of utmost importance to empower farmers to the maximum extent possible. Amongst their primary concerns, according to Bell (2015), small producers regularly identify the most important as “1) access to credit, 2) access to better market prices and 3) access to credible, relevant information.” FAO (2015) states that farmers' information needs are expected to only increase as they are faced with making increasingly complex decisions about the use of their land, the selection of the agricultural products they grow, the choice of markets to sell their agricultural products, and other necessary decisions that affect the livelihoods of their families and, more broadly, society.

Indeed, agriculture is becoming increasingly knowledge intensive. The development of information and communication technologies (ICTs) has provided new opportunities to address these challenges facing agriculture. Where once rural areas were largely disconnected from the greater world, today networks of ICTs cover the globe and represent a transformational opportunity for rural populations. According to FAO and ITU (2016), it has been widely demonstrated that enhancing the ability of farming communities to connect with knowledge banks, networks, and institutions and to fortify their linkages in their operations with other related sectors such as rural development, natural resource management, banking, insurance, media, governance, transportation, and logistics management via ICTs has improved their productivity, profitability, food security and employment opportunities substantially. Linking knowledge to innovation is also key to addressing information and knowledge gaps in the agricultural sector. ICTs can thus play a very important role in reducing these information gaps.

2. INFORMATION AND COMMUNICATION TECHNOLOGIES INVOLVED IN PROCESSING AGRICULTURAL DATA

ICTs have a variety of potential roles in the agricultural sector, from capacity building and empowerment to promoting environmentally sustainable farming practices to increasing access to financial services for rural communities. However, in this paper, I will specifically examine the role of ICTs that farmers and agricultural statistics institutions (henceforth referred to as ASIs) use to collect, manage, and disseminate agricultural data in select countries in North and Central America and the Caribbean. In this section I will introduce some of the prominent types of ICTs employed; in Section 3 I present a review of how ASIs in the countries studied in the region process agricultural data and how they currently implement ICTs in the agricultural sector; in Section 4 I analyze the benefits and challenges that ICTs bring to the region; and in Section 5 I offer my concluding remarks and thoughts for future research.

Historically, ASIs have collected data such as those related to prices, agricultural production, areas cultivated and harvested, and demographic information via traditional methods such as surveys and censuses, as well as other sources such as administrative and transactional data, and have distributed these data in periodic publications such as bulletins or reports. This remains to be the case; however, with the widespread use of telecommunications and other devices driven by innovations in technology, the statistics community is faced with the task of how to best incorporate the potential of these technologies to supplement and sometimes replace traditional methods of data collection and dissemination. Digital information is now continuously generated from sources such as GPS devices, scanning devices, automated teller machines, sensors, satellites, and social media. One of the biggest challenges of modern statistics is to find new tools to capture, manage, and process the high-volume, high-velocity, and large variety of these data, commonly referred to as Big Data.

The World Bank (2011) has identified a few main trends as the drivers of ICTs in agriculture, in particular for poor producers: "(1) low-cost and pervasive connectivity, (2) adaptable and more affordable tools, (3) advances in data storage and exchange, (4) innovative business models and partnerships, and (5) the democratization of information, including the open access movement and social media." This study has identified that these drivers have manifested into ICTs in three broad categories in the region: (1) smartphones and tablets, (2) information systems and social media, and (3) earth observation (EO) data. I will discuss each of these in more detail further in this section.

2.1 SMARTPHONES AND TABLETS

Mobile phones are at the forefront of ICTs in agriculture. The ability to purchase a low-cost mobile phone is complemented by the expansion in telecommunications infrastructure – as a consequence mobile phone subscriptions have risen to over 90% in the developing world (Bell 2015). The reach and affordability of broadband Internet has also improved dramatically in developing regions in the last couple of decades (Bell 2015).

Mobile phones and other smart devices have the potential to directly benefit the farmer in a number of important ways. One key benefit is the ability to easily push information to the farmer – such as market prices or weather reporting. According to Nakasone (2014), most evidence suggests that the spread of mobile phones leads to better market integration and to less price volatility. Access to mobile phones in rural areas seems to increase agricultural market performance, possibly through better arbitrage opportunities; even when farmers have little access, mobile phones still impact the functioning of agricultural markets because of widespread use by traders (Nakasone 2014). For example, in a study analyzing the rollout of mobile phones across grain markets in Niger, the introduction of mobile phones led to a "10-16% reduction in the dispersion of grain prices across markets (i.e., the absolute value of price differentials between pairs of markets) and to a 10% reduction in the coefficient of intra-annual price variation within markets" (Nakasone 2014). Nakasone (2014) states that the main reason for these reductions is traders' behavior: traders with mobile phones can search for sales opportunities across more markets, reducing the variability in consumer prices.

It is hypothesized that spatially disaggregated weather forecasts help farmers improve yields because they can take better anticipative action to deal with weather shocks; however, there has not been a study conducted to confirm such an impact (Nakasone 2014).

The proliferation of smartphones and tablets have also no doubt aided extensionists in compiling agricultural information in the field. The use of these technologies has drastically facilitated their work, i.e. conducting agricultural surveys as well as monitoring and evaluation. It allows for an initial validation of the data by the extensionist in-situ before being quickly transferred to ASIs for further validation and finalization.

Mobile phones also help the extensionist help the farmer in other tangible ways not directly related to collecting or disseminating data, to the extent that they can increase access to important financial services to rural communities, help to secure savings, find affordable insurance, assist with business planning, provide technical information or train, and obtain tools to better manage risk.

2.2 INFORMATION SYSTEMS AND SOCIAL MEDIA

As we'll examine in more detail in Section 3, many ASIs maintain information systems that serve as a central repository for agricultural data. These systems typically contain data such as price and production information collected from surveys or other sources, along with other products such as bulletins and research findings. In the absence of an information system, in many cases producers can find these data in some form on the ASI's website. The accessibility and user-friendliness of these systems are evidently of utmost interest to producers, who can leverage the power of the information contained within to assist in their decision making and planning.

Vast quantities of information held by ASIs and other actors are becoming visible, publicly accessible, and reusable through the open access movement in recent decades, and these actions have not only improved transparency and accountability as well as aided farmers in their decision-making, but have invited the public, private, and research sectors to participate in solving long-term economic and social problems (World Bank 2011).

Social media also has great potential to be used for knowledge sharing of data and collaboration in agriculture. In an international seminar on the use of Whatsapp in agricultural extension (ECLAC and FAO 2022), Claudia Ponce Quiroz explains that Whatsapp groups have been a versatile, cheap, and effective tool for extensionists in Chile to rapidly communicate information to many farmers at the same time, respond to technical consultations, and disseminate other content. They also have been useful for farmers to communicate with each other and have facilitated the marketing of products and services and the consultation of prices. Furthermore, Quiroz (ECLAC and FAO 2022) notes that the use of Whatsapp benefits agricultural extension because a record is kept in the application of all messages exchanged, the audio messages facilitate access to those who have trouble writing, the app is widely used by women facilitating direct communication to women producers in rural communities, and extensionists can make use of a user-friendly network that a large number of people are already using.

2.3 EARTH OBSERVATION DATA

Other key ICTs that are being implemented in agriculture are earth observation (EO) technologies such as satellites and drones, the images produced from which are an important source of data in the sector. Satellite images and other remote sensors have improved enormously in quality and detail and these tools use less energy and require less human attention than in previous years. Take as an example Figure 2, a satellite image generated from the website of the *Servicio de Información Agroalimentaria y Pesquera* (SIAP) of Mexico (Gobierno de México 2022), showing plots of land dedicated to cultivating corn (green) and sorghum (orange) in the Mexicali region:

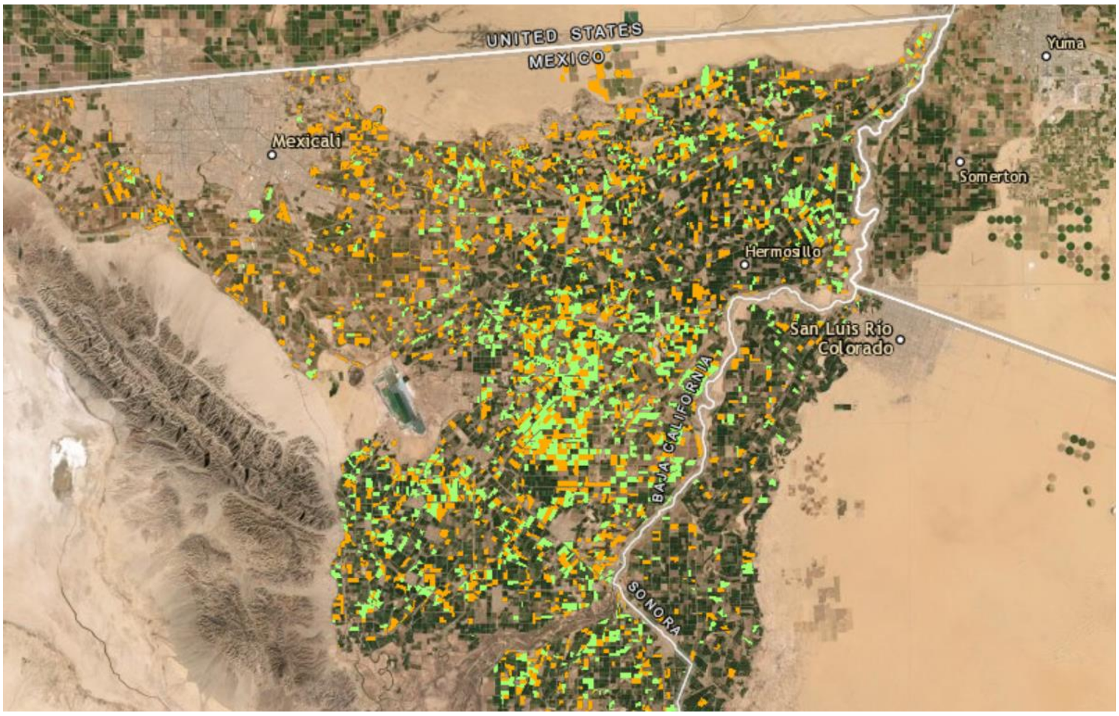

Figure 2 – Agricultural Land Use in the Mexicali Region. Source: Gobierno de México (2022)

These types of technologies can determine with great precision data such as crop location, type, yield, and productivity in a given area and overlay that data on an image. The United Nations Statistical Commission recognizes EO data as one of the cornerstones of the statistical modernization process in relation to the use of Big Data as an alternative or integrative source of information to traditional censuses and surveys to these types of variables, and to produce global land cover and land use statistics (UN-CEBD 2022). On a national level, crop acreage, yield, and productivity statistics are fundamental for the monitoring of and reporting on the agricultural production system allowing them to plan its commodity value chains, and to formulate efficient policies that ensure food security (UN-CEBD 2022).

According to the United Nations Task Team on Satellite Imagery and Geospatial Data (UN-TTSIGD), EO data have significant potential to provide more timely statistical outputs in the sector, to reduce the frequency of surveys, to reduce respondent burden and other costs, to provide data at a more disaggregated level for informed decision making and to provide new statistics and statistical insights (UN-TTSIGD 2017). They find that EO data may also support the monitoring of the Sustainable Development Goals (SDGs) by improving timeliness and relevance of indicators without compromising their impartiality and methodological soundness (UN-TTSIGD 2017).

As tools such as Microsoft Earth or Google Maps become more commonplace, geospatial information is becoming more accessible to nonspecialist users. Several ASIs have created substantial sets of georeferenced data through affordable, usable geographic information systems (GIS) applications accessible via their institutions' information systems or websites (such as SIAP's discussed above) using standard PCs and mobile devices. The capacity to overlay geospatial information with climate and socioeconomic data also opens many options for analyzing trends in the field such as erosion or the movement of pathogens, making projections such as the effects of climate change or the best location of wholesale markets in relation to transport infrastructure, and selecting particular groups to test new technologies or farming practices (World Bank 2011).

Another promising outcome of applying EO data to agriculture is what is known as precision agriculture. Traditionally in agriculture, crops are treated under the assumptions of uniform soil, nutrient, moisture, weed, and insect conditions. Occasionally this may lead to over- or under-applications of pesticides, irrigation, fertilizers, and other treatments; however, with the advent of geospatial information, producers can optimize returns on inputs while preserving resources by observing and responding to the spatial and temporal variability of soil and crop factors between and within fields (Tantalaki 2019). Thus, the collection of georeferenced data can generate more accurate descriptions of system aspects and help producers make more informed decisions associated with crop production, which logically would result in more returns for the producer.

Tantalaki (2019) comments that new challenges to the successful implementation of precision agriculture stem from digesting the huge increase of data being collected from a variety of Big Data sources, EO data being one of them. Despite these added layers of complexity, the challenge to efficiently extract insight from Big Data such as EO data can be tackled by using techniques such as machine learning and data mining (Tantalaki 2019).

In the following section I will mention some exciting initiatives of ASIs implementing EO data in Honduras, Mexico, and the United States.

3. CASE STUDY OF SELECT NORTH AMERICAN, CENTRAL AMERICAN, AND CARIBBEAN COUNTRIES

This work was carried out based on a survey of existing literature and information systems, as well as interviews with numerous country-level ASIs in the region. Naturally, the detail and breadth of responses received from each country varied. I had the opportunity to participate in these interviews as an intern under the supervision of José Manuel Iraheta Bonilla, Economics Affairs Officer in the Agricultural Development and Climate Change Unit of the Economic Commission for Latin America and the Caribbean

(ECLAC) regional headquarters in Mexico City. For a list of all institutions interviewed, with the dates they took place, see Section 6.

This section presents a review of how ASIs in 11 countries in the region – Panama, Costa Rica, Honduras, Guatemala, Mexico, El Salvador, Nicaragua, Cuba, Belize, the Dominican Republic, and the United States – currently manage the flow of agricultural data and how they are implementing ICTs in their respective countries.

3.1 PANAMA

The *Ministerio de Desarrollo Agropecuario* (MIDA) is the institution responsible for collecting basic information on production statistics and prices of agricultural activity, along with agricultural yields and areas cultivated and harvested. For this purpose, MIDA obtains information from the administrative records of the regional offices located in the interior of the Republic of Panama (ECLAC 2016). They also make use of information collected by extensionists in the field, which is compiled by regional agencies before being sent to MIDA. One difficulty that they have faced is that some producers do not register with the regional agencies and thus their agricultural information cannot be tracked, although they are motivated to do so in order to access certain social programs (Interview with MIDA Panamá, 2022).

MIDA is developing a new agricultural information system, *Sistema Integrado de Gestión Agropecuaria de Panamá* (SIGAP), that will be available to the public upon completion (Interview with MIDA Panamá, 2022). MIDA does not yet employ satellites, but it intends to make an agreement with a private company to utilize satellites to monitor the potential of agricultural land (Interview with MIDA Panamá, 2022).

The *Instituto de Mercado Agropecuario* (IMA) is another national institution that compiles price information via informants weekly in the country's main markets. These prices are made available on their social media accounts (Facebook, Instagram, and Twitter) and IMA is making an effort to promote these pages to disseminate more information (Interview with IMA Panamá, 2022). They generate online bulletins as well on a weekly basis for key products that had an abnormal behavior during the week.

IMA confirmed their interest in utilizing tablets to collect price information in the markets as some other Central American countries do, stating that the collection and validation process would be greatly expedited and simplified (Interview with IMA Panama, 2022).

3.2 COSTA RICA

In Costa Rica, we interviewed the *Secretaría Ejecutiva de Planificación Sectorial Agropecuaria* (SEPSA). SEPSA is a body responsible for assisting in the effective and efficient conduct of national agricultural development and produces the *Boletines Estadísticos Agropecuarios* every year, which include data on surface use, agricultural production, agricultural public spending, and consumer prices (Interview with SEPSA Panamá, 2022). These bulletins are made available to the public on their website. Once a year, SEPSA Costa Rica collects these data from several national corporations, such as CONARROZ and CORBANA, which specialize in compiling the information of a subset of agricultural products, such as rice or bananas (Interview with SEPSA Costa Rica, 2022).

3.3 HONDURAS

The *Fundación Hondureña de Investigación Agrícola* (FHIA) was the ASI we interviewed in Honduras. With the support of the Ministry of Agriculture and Livestock (SAG) and the private sector, FHIA administers two online platforms: INFOAGRO y SIMPAH (*Sistema de Información de Mercados de Agricultura y Ganadería*).

INFOAGRO was described as an easily accessible platform that consolidates timely information generated by institutions related to the agricultural sector both nationally and internationally, based on the identification of user information needs, facilitating consultation mechanisms for the decision-making process, both in the public and private sector (Interview with FHIA Honduras, 2022).

SIMPAH collects and disseminates the prices of the country's agricultural products daily through a network of technicians, who are mostly merchants located in the main wholesale markets. Technicians collect prices manually on paper, not through tablets or cell phones. This is due to the informal nature of the markets and for security reasons (Interview with FHIA Honduras, 2022).

Normally, the institution responsible for the collection of agricultural data is the National Institute of Statistics (INE). However, with the lack of funds to carry out an agricultural census or survey, the one who has made efforts to collect data on agricultural activity is the Directorate of Agricultural Science and Technology (DICTA) (Interview with FHIA Honduras, 2022). They have compiled this information through regional technicians via telephone calls that are held in different offices in the country.

With the support of the United States Department of Agriculture (USDA), DICTA has an initiative to use drones to collect agricultural data (Interview with FHIA Honduras, 2022). When this project might come to completion was not confirmed.

3.4 GUATEMALA

In Guatemala, we interviewed the *División de Planeamiento* (DIPLAN) of the *Ministerio de Agricultura, Ganadería y* Alimentación (MAGA) and the Bank of Guatemala (BANGUAT). Historically, statistics on agricultural production were generated by the *Instituto Nacional de Estadísticas* (INE) and BANGUAT, however BANGUAT stopped collecting production data in 2017-2018 (Interview with DIPLAN Guatemala, 2022).

BANGUAT manages terrestrial maps that show which sections of land in the country are used for agricultural purposes. These are not generated by satellite images but are based primarily on the agricultural census, the last of which was conducted in 2003. To complement information for the census, they communicate with associations and producers in the field to understand changes in land use and agricultural yields and use this information to estimate levels of agricultural production. The most recent maps created were in 2010 and 2020 (Interview with BANGUAT, 2022).

DIPLAN is currently responsible for collecting data on wholesale prices in the country. Since 2016 they have stopped publishing their periodic report *Agro en Cifras,* which contained areas harvested, tariff rates, prices, and production information, as well as various other demographic and socioeconomic data in the agricultural sector (Interview with DIPLAN Guatemala, 2022).

3.5 MEXICO

INEGI (*Instituto Nacional de Estadística y Geografía*) is a leading institution for the generation, processing, and dissemination of statistics on agricultural activity in Mexico. INEGI will carry out an agricultural census between September and November of 2022, the last census having been performed 15 years ago. The census will cover a universe of 4.3 million production units, and notably each producer may own several production units. The data will be collected by 3,000 interviewers using tablets, which will be very useful since it will allow them to visually chart out the producers on the map, incorporate validations in the questionnaires and quickly send the information to be validated and codified.

INEGI utilizes 3 questionnaires, one for forest producers, another for medium and small producers, and one for large producers. In these questionnaires they collect agricultural information such as crop production, prices, harvested area, agricultural technology used, whether the farmers have credit or not, whether they have insurance or not, whether they apply fertilizers or not, along with other sociodemographic data of the farmers. The strategy to capture this information is through a sweep of homes in towns with less than 15,000 inhabitants. For towns with more than 15,000 inhabitants, they use the directory of producers. INEGI pointed out that 93% of informants live in towns with less than 15,000 inhabitants (Interview with INEGI, 2022).

Since 2007, INEGI uses satellite images to estimate cultivation areas and land uses and validate information from surveys. They work together with Canada and NASA in this regard. Additionally, every two years they carry out agricultural surveys, compiling information on agricultural activity and prices. In the surveys INEGI utilizes probabilistic sampling, without weights, stratified by crop type (Interview with INEGI, 2022).

SIAP (*Servicio de Información Agroalimentaria y Pesquera*) is another institution in Mexico responsible for handling agricultural data. SIAP performs a detailed analysis of the production of 64 crops, 12 livestock products, and 3 fishery products per month, which make up about 90% of the country's agricultural GDP, and publishes bulletins on these. Notably, they have had to stop producing some bulletins (such as the bulletin on milk and its derivatives) and change the periodicity of others due to budget cuts (Interview with INEGI, 2022).

SIAP uses satellite images to corroborate and complement the information that is being collected by technicians in the field. These images also help to fill information gaps due to security difficulties and help monitor the implementation of support programs for small and medium producers (Interview with INEGI, 2022). They have also used unmanned drone flights to verify the number of cattle in the field (Interview with INEGI, 2022).

Regarding prices, their compilation is based on obtaining values of production. They monitor the first-sale prices, and the prices are weighted by zones of production to obtain a representative price of the municipality or region (Interview with INEGI, 2022). They also publish a daily wholesale price bulletin.

3.6 EL SALVADOR

The *Dirección General de Economía Agropecuaria* (DGEA) of the *Ministerio de Agricultura y Ganadería* (MAG) utilize a probabilistic method to carry out their yearly agricultural surveys, based on a universe of farmers from the agricultural census conducted between 2005-2007. Agricultural data on production, surfaces, and prices are published every year in the bulletins *Anuarios de Estadísticas Agropecuarias* and are available to the public online. DGEA also collects price information in the large markets via informants on a weekly basis and publishes reports on these prices monthly; these reports however are not available to the public except upon request (Interview with DGEA, 2022).

3.7 NICARAGUA

The *Ministerio de Agricultura* (MA) of Nicaragua was responsible for compiling basic statistics about agricultural activity until 2014. The MA managed to develop a system that monitored areas cultivated and harvested and agricultural production utilizing mobile devices which transferred information in real time via satellite technology to the servers located in the Ministry (ECLAC 2016). However, since 2015 the Nicaraguan government assigned the *Banco Central de Nicaragua* the responsibility of compiling agricultural information via surveys (ECLAC 2016). Neither the MA nor the *Banco Central de Nicaragua* were available for interview.

3.8 CUBA

The *Oficina Nacional de Estadística e Información* (ONEI) of Cuba is preparing to conduct an agricultural census, the last of which was carried out in the country over 60 years ago (Interview with ONEI Cuba, 2022). Until 2021 they compiled data on agricultural production and consumption via questionnaires on a monthly basis. Since then, this information has been captured via "*formas organizativas no estatales*," after which it passes through a series of validations at the regional and national level. Compiling price information continues to be a challenge for ONEI Cuba (Interview with ONEI Cuba, 2022).

3.9 BELIZE

The Ministry of Agriculture, Food Security, and Enterprise of the Government of Belize (MAFSEGB) utilizes an online platform named BAIMS (Belize Agriculture Information System), that can be accessed by smartphone, tablet, or computer. This allows the extensionists who compile agricultural information on production or prices to quickly perform an initial verification of the data before passing it along for further verification and finalization (Interview with MAFSEGB, 2022).

The section of BAIMS that deals with price information is still in development. It was discussed that in order to make more readily accessible, timely price information to smallholder farmers in the meantime for decision-making purposes, MAFSEGB could reference other regional information systems that contain agricultural price information such as SIMMAGRO (*Sistema Regional de Inteligencia y Monitoreo de Mercados Agrícolas*) of the Central American Integration System (SICA) (Interview with MAFSEGB, 2022).

3.10 DOMINICAN REPUBLIC

The responsible and leading institution in the Dominican Republic for the generation, processing, and dissemination of statistics on agricultural activity is the *Departamento de Economía Agropecuaria* (DEA) under the Vice Ministry of Agricultural Sector Planning of the Ministry of Agriculture (MA). The information is captured from the administrative records of the subregional headquarters of the MA within the country (ECLAC 2016). There are online records of data on areas cultivated and harvested, as well as data on agricultural, livestock, forestry, and fishing activities production processed by the DEA for estimating the volumes and prices of agricultural production.

To improve the compilation of agricultural information, MA is considering spending resources to design and implement an agricultural survey three times a year and using administrative records to complement the gaps in information left by the surveys (Interview with MA Dominican Republic, 2022).

MA has created an online platform named SIDIAGRO (*Sistema Digital de Información Agropecuaria*) in order to integrate timely price data in a common system. Prices are collected in the principal markets via tablets and uploaded to the system weekly (Interview with MA Dominican Republic, 2022). As of now this platform is only available internally in MA.

3.11 UNITED STATES

The United States is the one country that forms part of my research that is a “developed” nation – I included them in the hope of learning some things about their use of ICTs in agriculture that could be used as an example to the rest of the region.

Furthermore, as the country has received close to 20 million immigrants from Mexico, Central America, and the Caribbean over the last decades (Migration Policy Institute 2022), many of whom have been smallholder farmers directly or indirectly impacted by climate change and in search of a more hospitable climate for agriculture and better living conditions, the United States should be concerned about agricultural development south of its border. As discussed above, US agencies are already collaborating with at least Honduras and Mexico to implement EO technologies in agriculture.

The agency I interviewed was the National Agricultural Statistics Service in the United States Department of Agriculture (USDA-NASS). They report that an agricultural census is performed every 5 years, and that the majority of data they receive is via surveys which are mailed to producers (Interview with USDA-NASS, 2022). USDA-NASS carries out about 400 types of surveys of varying periodicities. A group of enumerators follow up with those surveys by phone or in the field, if necessary, where they are equipped with iPads to report information. Online self-reporting of data is also available and has been in use for approximately 15 years (Interview with USDA-NASS, 2022).

USDA-NASS (2022) commented that survey response rates have decreased over time and partially attributed this to what was described as an ever-increasing number of surveys that people have come in contact in society, not only within the agricultural sector. In order to reduce the number of surveys performed, they currently have research projects looking at incorporating other sources of data, including administrative data and data generated by precision agriculture (Interview with USDA-NASS, 2022).

One of the difficulties mentioned was obtaining data from some of these alternate sources. Precision agricultural data is often generated from producers or large equipment manufacturers and passing information from these sources to the UDSA in a meaningful way can be a challenge given the vast quantities of data that is often generated (Interview with USDA-NASS, 2022).

USDA-NASS started using geospatial data as a way to complement and improve crop estimates received from surveys. Since 1997 USDA-NASS has provided a product called the Cropland Data Layer which breaks down the country in 30 meter by 30 meter pixels and uses geospatial information and a machine learning model to predict what is grown in each area. This product is available to the public. They admit that processing geospatial data requires a lot of computing power and is very costly due to the enormous quantity of data involved, therefore they continue to research and evaluate whether the benefits outweigh the large costs involved (Interview with USDA-NASS, 2022).

A useful byproduct of their geospatial work is the ability to conduct disaster analysis from the resulting data to predict hurricanes, floods, droughts, and the like and their effect on agriculture. With this information USDA can offer assistance to producers affected by such extreme events.

USDA-NASS (2022) stated that their transparency with sharing their long history of data collected and methodologies has contributed to increased public trust in them.

4. ANALYSIS OF RESULTS

4.1 BENEFITS AND IMPLICATIONS FOR FOOD SECURITY AND RURAL DEVELOPMENT

Although an effective implementation of ICTs in agriculture would require prior research and potentially significant investment, it has the capability to save a lot of resources in the long term and bring tangible benefits to small- and medium-size producers as argued below. Throughout the scope of this work, I have found that the benefits of the implementation of ICTs in agriculture can be comprised of the following broad categories, consistent with the FAO and ITU's publication *E-agriculture strategy guide: Piloted in Asia-Pacific countries* (2016): transformation of information flow and decision-making processes, reduction of individual and institutional risk, and stimulation of investments.

Considering these benefits listed above, it is evident how the implementation of ICTs can help attain food security and rural development goals. FAO, IFAD, and WFP – three United Nations agencies located in Rome responsible for promoting the production, distribution, and consumption of nutritious food among the population, mainly those living in poverty and social exclusion – finished in 2014 a debate regarding the goals and indicators for food security, nutrition, and sustainable agriculture, within the framework of the SDG agenda for the year 2030 (ECLAC 2016).

The goals were the following: Goal 1, *Access to food*: all people have adequate access to adequate food (safe, affordable, diverse, and nutritious) throughout the year; Goal 2, *Malnutrition*: end malnutrition in all its forms (malnutrition, micronutrient deficiency and overnutrition), with special attention to completion of stunting; Goal 3, *Sustainable food systems*: all food production systems become more productive, sustainable, resilient, and efficient, while minimizing adverse environmental impacts without compromising food safety and nutritional; Goal 4, *Productivity and income of smallholders*: all smallholder food producers, especially women, have secure access to inputs knowledge, productive resources and services to increase their productivity on a sustained basis while improving their income and resilience; Goal 5, *Food losses and waste*: food post-production systems more efficient (harvesting, handling and storage, processing and packaging, transport, and consumption), which reduce the global rate of food loss and waste by 50% (ECLAC 2016). In this section I will elaborate on how the above-mentioned benefits contribute to these goals.

4.1.1 **Transformation of information flow and decision-making processes**

First, ICTs in agriculture have the potential to transform the way farmers and ASIs collect, analyze, store, and share agricultural information for their daily decision-making purposes (FAO e ITU 2016). As mentioned previously, a clear example of this is the effective dissemination of price information. in many cases, farmers in rural areas are not well informed about prevailing market prices. Therefore, they may not sell their products in the most profitable markets or may accept lower prices from middlemen, leading to the misallocation of resources and inefficiencies in the agricultural supply chain (Nakasone 2014). ICTs can help in reducing the layers of intermediaries and can make transactions unbiased and transparent, thus improving vertical and horizontal linkages in the supply chain and helping develop trust-based relationships between value chain actors (FAO e ITU 2016). Therefore, by providing timely price information to the farmer, ICTs help contribute to Goals 3 and 4 listed above.

Additionally, lower transaction costs, less information asymmetries, improved market coordination and transparent rural markets resulting from ICT implementation leads to greater efficiencies in rural markets and reduces wastage in various stages from the field-to-fork value chain (FAO e ITU 2016). ICTs can also improve food management through more efficient information flow and improved traceability and help deliver more efficient and reliable data to comply with international traceability standards, ultimately leading to improved food safety (FAO e ITU 2016). It follows that by facilitating this real-time information exchange, ICTs also contribute to Goals 1 and 5.

On the other hand, as discussed above, on the policymaker level, having access to timely, complete data on crop acreage, yield, and crop productivity are crucial to plan commodity value chains, and to formulate the most efficient policies possible that ensure food security (UN-CEBD 2022). ICTs not only help provide timely, complete data, but also provide a means to efficiently monitor a policy's progress, helping to contribute to all Goals listed above. SIAP Mexico provided an example of this: they reported that by using satellite images to corroborate and complement the information that is being collected by technicians in the field, they can better monitor the implementation of support programs for small and medium producers (Interview with SIAP, 2022).

Not least, ICTs empower agricultural extensionists in the field to support and exchange information with producers as effectively as possible, leading to potential contributions across all Goals for food security and rural development.

4.1.2. **Reduction of individual and institutional risk**

ICTs in agriculture can be leveraged to reduce uncertainty and enhance preparedness and response to climate change, disasters, and even security risks. In the

United States, USDA-NASS can monitor agricultural disasters in near real-time and provide quantitative assessments using remotely sensed data and geospatial techniques (Interview with USDA-NASS, 2022). In Mexico, satellite images have been used to safely fill information gaps due to security difficulties involved with conducting agricultural surveys or censuses in certain regions of the country (Interview with SIAP, 2022). By helping address these risks, ICTs contribute to Goals 3 and 4.

4.1.3. **Stimulation of investments**

ICT development stimulates investment in broadband services and telecommunications infrastructure in rural areas and ultimately human capital, creating positive effects for the entire rural community. FAO (2016) explains that the cross-sectoral nature of ICT propels growth in other sectors that can be further leveraged by agriculture communities. For instance, the use of "data gathering and data analytics by weather departments can make micro-insurance more efficient, and the deployment of mobile banking or mobile money by the telecom and banking sector can significantly ease financing, transactional, social safety, and investment challenges" (FAO e ITU 2016). Equipped with these tools and protections, farmers and nonfarmers alike in the rural community can take a smarter and more aggressive approach with what they produce, meaning a higher earning potential, contributing to Goal 4.

Moreover, with the implementation of geographic information systems, governments can better plan where to further invest in agricultural and livestock infrastructure such as centers to store grains, slaughterhouses, and fattening centers, contributing to Goals 1, 3, and 5.

4.2 CHALLENGES

Amongst some of the key findings was that no North American, Central American, or Caribbean country interviewed, apart from Mexico and the United States, had the resources to perform an agricultural census, with many agricultural departments having faced budget cuts in recent years. Many countries had not performed a census in the last decade, sometimes in the last several decades. Agricultural surveys also require extensive resources and planning in order to design them to be as representative as possible of the target population and generate data that is as close to reality as possible. Censuses and surveys also require adequate manning, which was another factor with which many countries reported having difficulties. Therefore, it is understandable that, faced with these difficulties, implementing ICTs may not be the top priority of many countries in the region, as they simply do not have the resources to invest in such technologies.

Along with a lack of resources and manning, security was also an issue that countries reported regarding the implementation of ICTs, particularly when it came to extensionists utilizing tablets or other devices to collect price or production information in certain markets. In these cases, the extensionists often resorted to collecting data manually using pen and paper, which significantly delayed the subsequent reporting and verification process.

5. CONCLUSIONS, CONTRIBUTIONS, FUTURE RESEARCH

This work is important in that it offers an update of advances that ASIs in the region have made in recent years and in the context of the COVID-19 pandemic regarding their information systems and implementation of other ICTs in their respective countries.

It indicates that certain ICTs have already brought several important benefits to parts of the region and suggests that the rest of the region could equally benefit from their implementation. It is hoped that this paper spurs further interest and research about how ICTs can improve the livelihoods of farmers in Mexico, Central America, and the Caribbean.

Although the implementation of ICTs in agriculture holds much promise, there is still research to be done to confirm its utility and practicality in some respects. For example, as discussed above, while it is hypothesized that spatially disaggregated weather forecasts help farmers improve yields because they can take better anticipative action to deal with weather shocks, there has not been a study conducted to confirm such an impact (Nakasone 2014). Furthermore, as USDA-NASS pointed out, the costs involved with initial investments in and maintenance of EO data, including the manning involved with combing through and making sense of the staggering amount of data that is generated and available to ASIs to analyze, can be significant (Interview with USDA-NASS, 2022). Studies demonstrating this cost-benefit analysis would be an important topic of future research.

However, as discussed, there is clear evidence of the benefits that ICTs can bring to the agricultural community. The intuitive design of technologies such as smartphones and their capacity to convey information visually or audibly make them a useful tool to all farmers, including those with limited formal education or exposure to technology (World Bank 2011). And as the purchase price of phones, laptops, scientific instruments, and specialized software has steadily decreased over recent decades, it is clear that these instruments will only play an increasingly larger role in the day-to-day lives of rural communities, as well as in the role of ASIs serving these communities.

Where once rural areas were largely disconnected from the greater world, today, networks of ICTs enmesh the globe and represent a transformational opportunity for rural populations, enhancing the ability of farmers to connect with the knowledge, networks, and institutions necessary to improve their productivity, food security, and employment opportunities, while empowering governments, armed with more timely and a greater quantity of data, to best formulate policies to improve the livelihoods of their populations (World Bank 2011). Nonetheless, challenges stemming from climate change and a lack of resources and adequate manning in ASIs across the Central American and Caribbean region remind us that realizing this opportunity requires a long-term commitment to mobilizing appropriate resources and expertise.

6. INTERVIEWS WITH ECLAC

ASI (COUNTRY)	Date of Interview
BANGUAT (Guatemala)	19 July 2022
DIPLAN-MAGA (Guatemala)	23 June 2022
FHIA (Honduras)	7 September 2022
IMA (Panama)	22 June 2022
INEGI (Mexico)	30 June 2022
MA (Domican Republic)	15 June 2022
MAFSEGB (Belize)	17 June 2022
MAG (El Salvador)	24 June 2022
MIDA (Panama)	13 July 2022
ONEI (Cuba)	20 July 2022
SEPSA (Costa Rica)	14 July 2022
SIAP (Mexico)	20 July 2022
USDA-NASS (USA)	18 August 2022

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