

Remote Sensing Applications for Agriculture: A Feasibility Study

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Introduction

With the development of geospatial and imaging technologies, the potential application for the agriculture industry increases. Remote sensing is becoming a vital part of agricultural research and crop mass-production, especially in areas with limited available labor. This technology can benefit farmers by helping them maximize their input costs and increase yields (Santhosh, 2003.) However, many of these innovations are inaccessible to rural producers, and if they are available, farmers often lack the required skills and knowledge required to use the technology effectively. As technology availability and adoption progress, knowledge transfer and application will become equally important. This paper aims to identify these applications of geospatial technologies for farms who have access to these tools. These applications were researched through a feasibility study that was conducted with a large scale cacao operation in Ecuador.

Background and Context

Remote sensing is the practice of using scientific data-recording instruments that do not directly contact the targeted specimen or area. In addition, this field contains the interpretation and application of this data. On a large scale, remote sensing assists the task of land classification, making it possible to even distinguish sub-classes of similar ground type. It also aids efforts in managing changes to the earth's surfaces such as natural disasters, vegetation changes, or urban development. Compared to manual data collection, remote sensing is more time and labor efficient because it can cover large areas of land in a short time. It enables scientists to track and analyze physical

conditions, all the while recording the coordinates, or geolocation of the selected attributes. (Khoram, 2012). This requires the remotely sensed data to be related to physical measurements. These quantifiable relationships give insight into how the information might be utilized. These applications are used in many sectors, including agriculture and, in the context of this paper, application to the farm level.

Agriculture has been proven to have a significant impact on the economy of developing countries (DFID, 2014). This industry has an important effect on the gross domestic product of these nations and is often targeted by economists to contribute towards poverty reduction (Cervantes-Godoy). This is why intentional and focused efforts are made to stabilize or improve food systems along the entire market chain, because of their capability to improve both food security and economic capacity. These endeavors take many forms such as NGO efforts, extension services, policy writing, government projects, and technological innovations. In this case, current geospatial technologies will be examined and how it might contribute towards improving agricultural operations.

Farm managers aim to maximize input costs such as labor, water, pesticides, seeds, and fertilizer. Remote sensing offers the ability for farmers to analyze their required inputs by giving data on each plant or study area, indicating individual needs. This specialization is called precision agriculture. On a similar note, this technology gives the opportunity for maximizing yields due to the ability to monitor the crop health of an entire area. For example, a nitrogen deficient area can receive more fertilizer in order to produce its maximum yield. Precision agriculture requires heavy data collection

and research in order to make actual input suggestions. However, these recommendations are typically only studied and identified with major commodity crops such as corn, wheat, and rice.

The demand for chocolate, which cacao is the main ingredient for, has gone up 17% in the decade, particularly in India and China (WCF, 2014). To meet this demand, farmers had to start producing more cacao. Since 2000, global production has increased by 50% (Wessel and Quist-Wessel, 2015). This increase has been primarily due to newly farmed areas, which has forced large amounts of deforestation. Sustainably increasing production per unit area is becoming the only viable solution to the high demand of cacao due to the environmental impact of farm expansion. Research, new technologies and better farming practices will contribute to higher yields in order to meet rising demands for cacao.

15% of worldwide cacao is grown in South America and, in this region, the top producing countries are Ecuador, Brazil, and Colombia (WCF, 2014). 90% of this cacao is grown on small-scale, family owned farms. These farmers rely on their cacao yields for their primary source of income. For them, growing more cacao means higher profits. Research studies in Malaysia have shown the possibility of reaching 6300 kg/ha in cacao yields (Yapp and Hadley, 1991). While these high yields are found possible, actual yields in South America average 400-500 kg/ha. Farms that grow the CCN-51 intensively variety average 907 kg/ha, but can reach up to 2721.55 with intensive practices (Boza, 2014).

There are several factors that lead to persistent yield gaps in cacao. Pest and disease dramatically reduce yields. Common diseases include Witches Broom (*Moniliophthora perniciosa*) and Frosty Pod Rot (*Moniliophthora roreri*). The cost of maintenance for healthy farms that effectively control disease often exceeds the producer's budget (van Vliet and Giller, 2017). Additionally, declining soil conditions lead to reduced production. Likewise, farmers are hesitant to invest in large amounts of fertilizers and manually manage soil nutrients. This is because fertilization rates for cacao are not clearly identified and proven, which is why it is uncommonly practiced in cacao farming (Miller, 2019). To address this issue, D.Snoeck et al. conducted a study in order to make a fertilization recommendation map of Ghana. This study used several modeling techniques along with remote sensing data to make the identified recommendations.

Climate change has impacted cacao production and will continue to do so as it intensifies (Laderach, 2010). This is due to both the annual temperature and precipitation fluxuations. Since most cacao farms are entirely rain fed, alterations in these patterns disrupts the production cycle. This might push the industry towards improved irrigation systems, which is common for intensive cacao production. Another limiting factor is the available sunlight for cacao trees. This remains to be one of the questions amongst cacao researchers, to determine the optimal amount of sun vs. shade for the trees. Geospatial studies and LiDar imaging pose great tools in analyzing available sunlight for tree canopies, and should be utilized to answer this research question.

Introducing Mars La Chola

This feasibility study aims to analyze the remote sensing tools owned by Mars La Chola and was initiated May 2018. This farm is 500 hectares and was acquired by Mars Incorporated in 2016, but was first started in 1997. The farm is situated 40 miles away from Ecuador's largest city, Guayaquil. It is divided into 3 major sectors, then subdivided into 32 lots, ranging from 4-34 hectares. This area has a tropical savanna climate, with a rainy season that runs from January to April. The daily average temperature ranges from 28-32 degrees Celsius. The farm location and climate conditions make it an optimal area for growing cacao.



Figure 1: Mars La Chola

In terms of genetic varieties of cacao, Nacional and CCN-51 are grown on La Chola. The Nacional variety offers an excellent flavor and market price, while the CCN-51 variety “has a higher resistance to climate conditions and pathogens and higher yields than other cocoa types and therefore is popular for cultivation by Ecuadorian farmers” (Hermann et. al, 2015). 30% of the farm has shaded cacao, meaning it is grown along side scattered native trees. This farm is unique because it has access to several pieces of remote sensing technology. Although this is uncommon for cacao farms, it is necessary for this study and if proven effective and feasible over time, might increase popularity among cacao farmers.

La Chola is a carefully managed cacao farm with around 160 employees. During the dry season from May to December, the farm is irrigated through a network of pipes that connect to sprinklers and drip devices. During the rainy season, no additional irrigation is necessary. Pesticides are applied as needed in localized areas. The farm is also fertigated and pruned on a bimonthly basis. When pruning, the cuttings are left on the ground to eventually become organic matter for the trees, as this has been an issue for the soil. Most of the soils on the farm are inceptisols and several areas display high salinity.

Feasibility Study Contents

For this feasibility study, direct contact was had with the research and development team at Mars La Chola. This team consists of seven Ecuadorian scientists who operate on the farm, conducting data gathering and a wide variety of agronomic research pertaining to cacao. Two specific members of this team who collaborated on

this study are working to maximizing the use of remote sensing instruments. They are also working to manage the vast datasets that come from the farm by using a software called AgStudio. During this study, a summer visit to La Chola was able to further develop the understanding of current field applications of this technology. During the farm stay, the GIS database was designed for the farm and the team was worked with to capture drone images of several plots of cacao. In addition, each piece of remote sensing equipment was inspected.

One of the common applications of GIS is to store, manage, and visualize large data sets. For La Chola, Microsoft Excel is currently used to record farm data such as lot information and yield. One of the project goals was to construct a GIS based platform for La Chola to visualize farm data. For the GIS software, ESRI ArcMaps was initially used, however the La Chola research team preferred QGIS due to its open source platform and the model was transferred to QGIS. The La Chola staff contracted a company to make a map of the farm, which distinguishes each lot. In order to put this information into a GIS software, the farm map had to first be georegistered. This is the process of placing the map precisely on the location that it represents. For this to work, the GIS file must be in the same coordinate system as the formulated map. In this case, the World Geodetic System 1984 (WGS84) was used. After this, the map and farm lots were digitized into a vector shapefile as can be seen in *Figure 3*. The farm data excel file was then joined to each lot in the GIS file, so the information for each lot could be accessible through GIS as a shapefile attribute table. In addition to the lot information, the La Chola research team followed these steps to make a digital soil map of the farm

which can be seen in *Figure 5*.

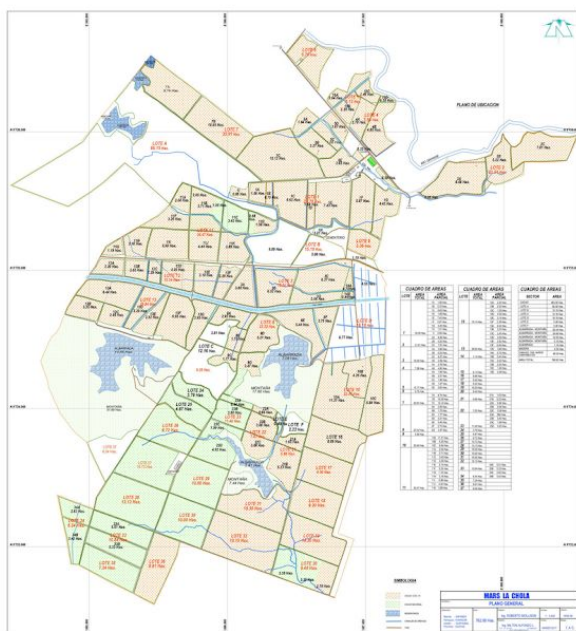


Figure 2: Zone Map

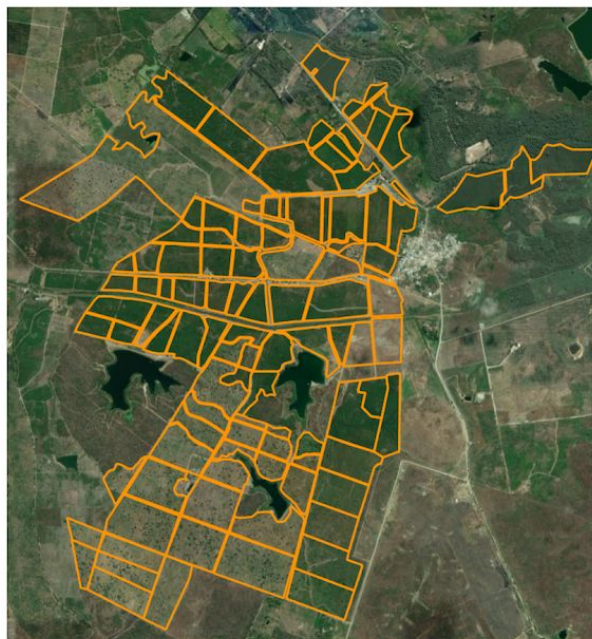


Figure 3: Digitized Zones

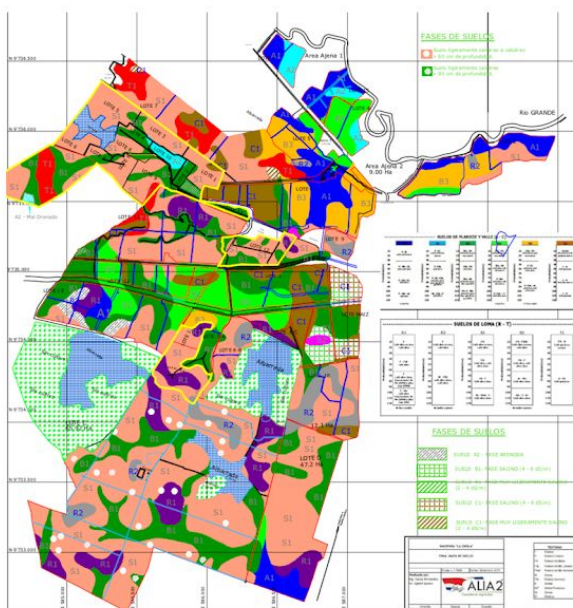


Figure 4: Soil Map

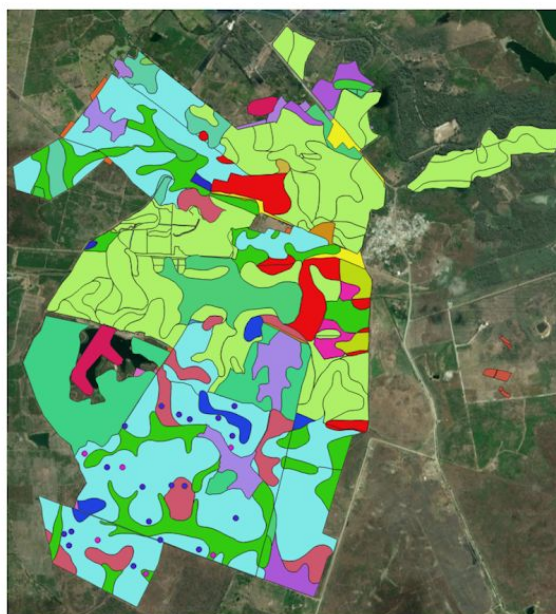


Figure 5: Digitized Soils

During this study, aerial imagery data was collected and stored on a cloud platform. This allowed easy sharing and collaboration for the large datasets, which contained aerial photos of several cacao plots. The flights were conducted near the end of the dry season in November. The images were taken at an elevation of 65 meters, using a software called Drone Deploy to choose the flight plan and settings. 75% overlap was used when recording the imagery. The R&D team has a DJI Inspire 2 drone that is used for the aerial imaging and a Parrot Sequoia camera that is used for recording the imagery. Due to the light sensitivity of the camera, the flights were only executed on days with either full sun or overcast. Spotted clouds are undesirable when capturing images due to the fluctuation of radiation intensity on the camera sensor.

The Parrot Sequoia captures standard RGB images by using a Visible 16 MPixel with a frame size of 4608×3456 pixels. These images are taken at lower elevations than satellites and can be used for farm visualization and mapping. For the chosen elevation, this resulted in a resolution of 1.75 cm/pixel. This map can be seen in *Figure 9*. This device also has a sensor that is also able to capture four different wavelengths at 1.2 MPixel with a frame size of 1280×960 , or commonly known as bands. These include the green, red, red-edge, and near infrared bands and has a wavelength range of 550-790 nanometers. The camera sensor is able to record the reflectance of radiation from the sun's energy on each pixel. "The amount of radiation reflected from plants is inversely related to radiation absorbed by plant pigments, and varies with the wavelength of incident radiation" (Santosh, 2003). Wavelength zones can be interpreted singularly, or they can be manipulated and combined to formulate complex

observations. For the chosen elevation, the reflectance recordings had a resolution of 6.5 cm/pixel.

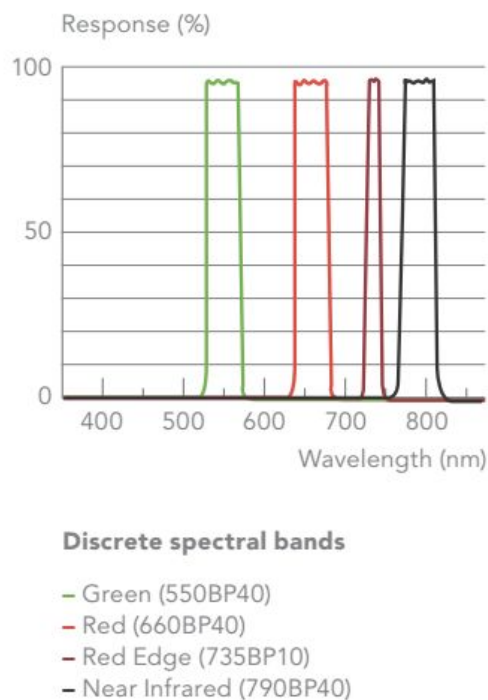


Figure 6: MicaSense electromagnetic band illustration

Once the images were taken, they needed to be stitched together. This is the process of turning hundreds of pictures into one file, known as an orthomosaic. For this process, a software called Pix4D Mapper was used. The La Chola research team does not currently have the necessary license to use this program, so this study was necessary for the farm to process these images. This software takes the geo-location information from each picture and combines the photos so that no overlap is shown. This software is also able to calculate different values for each pixel, based on the desired band math. These set of values are commonly called an index. Other imaging

softwares such as ENVI can do complex band math. Based on the chosen equation, they help display a map of certain qualities and properties.

One of the indices studied in this project was the normalized difference vegetation index (NDVI). These pixel values correspond to a band math equation that uses the red and near infrared wavelengths to give a value that represents vegetation health. Originally, this results in a black and white image where each pixel has a value from zero to one. It is common to apply a green color theme to this index. In annual crops, this index is used to monitor the phenological stages and developments. Currently, no studies have shown a physical correspondence to NDVI in cacao, other than providing a visual representation of healthy canopies. This might help farmers spot areas that need inspection for pests, disease, irrigation deficiencies, and other detrimental factors. A timeline of NDVI maps will indicate areas of growth, as well as areas that are receding in health. This is why this index is also used for monitoring deforestation. For example, in *Figure 7*, it is possible to determine alternate tree species in this cacao grove. This could help farmers gain environmental certifications for their farms in order to get a higher price for their cacao. Overall, NDVI is a helpful index for cacao farmers to visualize the health of their groves.



Figure 7: NDVI Original

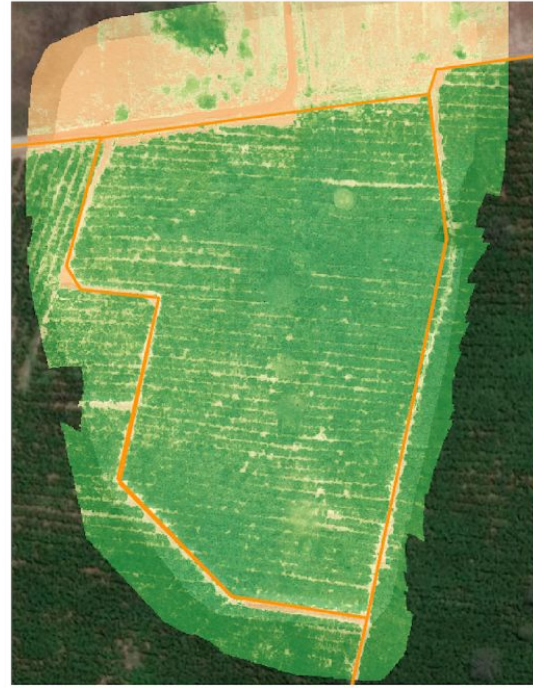


Figure 8: NDVI with Gradient

One of the field measurements taken during this study was leaf area index, or LAI. The instrument used for this data collection was a CI-110 Plant Canopy Imager. This calculation is acquired by finding the ratio of leaf surface area to ground surface area. Essentially, this measures how much light penetrates the canopy and is used in developing models for cacao production (Zuidema and Leffelaar, 2002). This value has a direct effect on the photosynthetic capabilities, and finally the biomass production of the tree. Since this farm prunes, they have the ability to choose the canopy density. The optimum density Theoretically, as LAI increases, the amount of chlorophyll increases in the plant. As these measurements are taken, the coordinates are also recorded. This

way, the farm can track data with a map to identify any spatial patterns of LAI. This can be seen in the figure below.



Figure 9: LAI Samples

Conclusion

The applications for remote sensing on cacao farming are at the beginning stages. It has great potential to help farmers make informed decisions and investments. Mars La Chola has a unique position to help prove these applications, as most cacao farms in the world do not have access to this technology. However, this might change in the future with increasing satellite image resolution and daily monitoring. For now, drones are the best way to collect high resolution imagery. To capitalize on this

opportunity, the research and development team at La Chola needs to record the coordinates of their observations during studies. For example, the team is currently conducting a study about the flushing and flowering habits of the cacao trees. GPS data would make it possible to analyze this topic spatially and to identify any trends based on tree location. The research team also needs to get the appropriate software licensing in order to do image processing in the future. Remote sensing technologies are a efficient way to both store and display data. It plays a crucial role in research as well. Mars La Chola manages large historical datasets, as well as recording new data from the field. Even though there are not yet precision agriculture recommendations for cacao like there are for commodity crops, it can still use these instruments to make informed decisions on crop management.



Figure 10: Cacao Grove



Figure 11: Cacao Pods

Citations

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