ENHANCING SATELLITE IMAGE MONITORING AND EARLY WARNING FOR PANAMA DISEASE OF BANANA IN CENTRAL AMERICA

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ABSTRACT: Central America is one of the major regions for banana cultivation, making it highly vulnerable to the threat of Panama disease. This disease causes yellowing, wilting, and reduced yield in banana plants, resulting in significant impacts on farmers' income and the economy of the region. To address this issue, the Taiwan Space Agency (TASA) and the International Cooperation and Development Found (TaiwanICDF) have collaborated to develop an effective monitoring and early warning system. In this study, a multi-temporal satellite image cloud storage and processing system, known as Taiwan Data Cube (TWDC), has been utilized. The system enables regular acquisition and analysis of satellite imagery from Formosat-5 and Sentinel-2 satellites. These high-resolution images provide valuable surface observation data, assisting in assessing the health status of banana plants and tracking disease development trends. The project has established 11 monitoring areas in Guatemala and 4 in Belize, covering a total area of 136.26 hectares. Spectral indices such as NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) have been employed for uniform random sampling within the monitored banana plantations. This data has been used to build a healthy growth model, which is continually refined based on the latest monitoring information to ensure accuracy and stability. The probability of plant health is determined through statistical analysis, enabling the assessment of plant condition. The research findings also demonstrate the feasibility of utilizing satellite resources for large-scale plant disease monitoring, as evidenced by successful collaboration with the Central American Plant Disease Prevention and Control Exercise. This development provides valuable information to farmers and disease control authorities, facilitating more effective disease monitoring and management practices.

1. INSTRUCTION

1.1 Objective

This research is a collaborative effort between the Taiwan Space Agency (TASA) and the International Cooperation and Development Foundation(TaiwanICDF)), utilizing Data Cube as a platform to analyse multi-temporal satellite imagery spectral data from banana cultivation areas. The goal is to establish characteristics of banana yellow leaf disease for early detection and response in collaboration with the Plant Health Authorities of Central American countries and allied governments. The aim is to identify and implement mitigation measures in potential disease outbreak hotspots before a large-scale epidemic occurs. Central American allies, including Guatemala and Belize, generate an annual banana export value exceeding 1.8 billion USD. Therefore, controlling banana yellow leaf disease is a crucial agricultural policy focus for Latin American allies and other banana-exporting nations in the region. The invasion of a large-scale plant disease in Central America could result in losses exceeding billions of dollars and the disappearance of numerous job opportunities. In order to assist our allied nations in effectively monitoring the health of banana-producing regions, the International Regional Organization for Plant and Animal Health (Organismo Internacional Regional de Sanidad Agropecuaria, OIRSA) submitted a concept paper to the International Cooperation and Development Foundation in early December 2019. This document specifically highlights the hope that our country can assist the organization's member nations within its jurisdiction in developing a more proactive and effective epidemic monitoring mechanism through remote sensing technology to prevent disease spread.

1.2 Data Cube for Central America

To effectively achieve the goal of cloud computing, the Data Cube system is currently deployed at the National Center for High-Performance Computing (NCHC) (Figure 1). The service offerings include satellite image data acquisition and analysis pattern computation services. In the satellite data acquisition service, Sentinel-2 is primarily used as open-source optical satellite data, along with high-resolution FORMOSAT-5 images for image analysis. Sentinel-2 provides open-source optical satellite data with a 10-meter resolution and is mainly used for routine imaging. A satellite data can be obtained every five days, so a procedure has been developed to automatically download Sentinel-2 data from the Copernicus Open Access Hub to accumulate data from target locations regularly in the future.

On the other hand, FORMOSAT-5 provides optical data with a 4-meter resolution and is characterized by autonomous imaging, allowing routine imaging of specific target areas. During the process, the lower-resolution data from Sentinel-2, along with historical high-resolution FORMOSAT-5 image data, are used for detailed spatial change analysis in specific disease-prone regions.

Regarding data preparation, as this proposal involves multi-temporal data analysis, acquired satellite data undergo pre-processing tasks, including geometric correction, radiometric calibration, and quality indicators. Finally, Analysis Ready Data (ARD) is generated. The prepared ARD is then imported into the Data Cube, and through the Data Cube development environment interface, multi-temporal satellite data can be directly analysed, completing the application and management module functional assessment of the Data Cube platform (Open Data Cube, 2020).

Figure 1. Data Cube system architecture

1.3 Study Area

This project has completed the establishment of a Data Cube for Central America and continues to collect local imagery, which is integrated into the Data Cube as the foundation for long-term monitoring data. Currently, through cooperation with the International Cooperation and Development Foundation (TaiwanICDF) and local government agencies, monitoring areas have been planned and established in 11 monitoring zones in Guatemala and 4 monitoring zones in Belize, with a total monitoring area of approximately 136.26 hectares (Figure 2). The project's ultimate goal is to complete monitoring deployment covering a combined area of 200 hectares in these two countries.

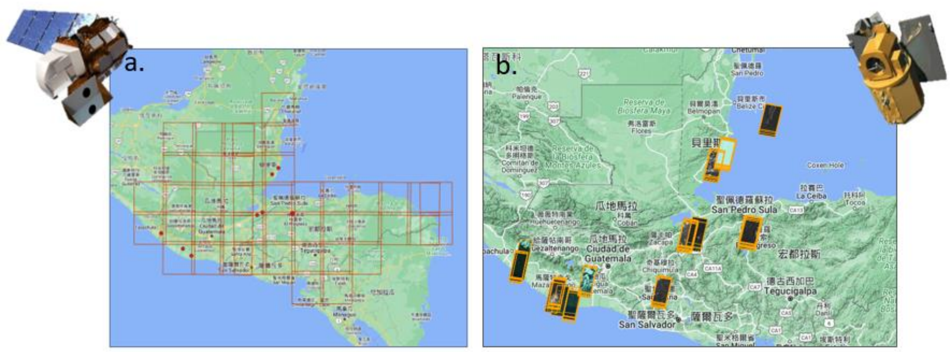


Figure 2. (a)Sentinel-2 data collection area, The red dots represent the locations of the observation fields. (b) FORMOSAT-5 data collection area.

2. ANALYSIS MODE

2.1 Mode description

This research involves the development of a large-scale plant disease monitoring model using multi-temporal satellite imagery. The development is divided into three main parts, which include rapid preview of historical farm data, establishment of plant growth models, and the development of anomaly detection patterns. The application of remote sensing technology for the analysis and monitoring of banana yellow leaf disease in this study will be complemented by the Data Cube, a multi-satellite data integration platform proposed by the Committee on Earth Observation Satellites (CEOS) in recent years. This platform effectively integrates diverse and multi-temporal satellite image data and provides mechanisms for building an online analysis platform. It utilizes satellite data and calculates relevant indicators to assist in capturing phenological changes and conducting monitoring. In this chapter, we will provide explanations for the development of the three parts: rapid preview of historical farm data, establishment of plant growth time models, and construction of anomaly detection patterns.

2.2 Multi- temporal satellite images

The portion of rapid historical farm data preview in the research is configured to output four types of data, including: natural color satellite image data, near-infrared (NIR) image data., vegetation index data (Normalized Difference Vegetation Index, NDVI), water content index data (Normalized Difference Water Index, NDWI) (Figure 3.). These four types of data are crucial for image interpretation. The natural color images, composed of the Red, Green, and Blue spectral bands, assist in quickly previewing the real surface conditions, mimicking the visual spectrum as perceived by the human eye. Near-infrared light, in particular, is not absorbed by chlorophyll and is used to differentiate between plants and bare soil based on the primary reflectance characteristics of vegetation (Cao, 1996). The Vegetation Index data (NDVI) is employed to monitor the quality of plant growth and effectively reflects plant physiological characteristics, making it a precise tool for monitoring plant health (Rouse et al., 1974). Finally, the Normalized Difference Water Index (NDWI) is used to determine the relationship between banana yellowing and water content (Chen, 2002). By utilizing rapid preview images and computing NDVI and NDWI indices, the objective is to initially assess recent plant growth conditions through image interpretation and aid in identifying the locations of healthy plant areas and suspected disease-prone areas.

2.3 The spectral indices of healthy plants follow a Gaussian distribution.

Utilizing the Central American Data Cube platform for the development of analysis modules and executing monitoring model development, the process begins by dividing each monitoring field into 20 areas. The purpose of this division is to enable local farmers to identify specific locations. Healthy plant positions are then extracted from these 20 areas. Through Sentinel-2 imagery, a multi-temporal analysis of NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized Difference Water Index) is conducted across the extensive banana plantation area.

A statistical model for the temporal growth of healthy banana plants is developed using the spatial spectral indices Gaussian distribution (Figure 3). This model is utilized to calculate the probability of plant health for the test locations and distinguish whether their health conditions are abnormal. Additionally, when diseased locations are confirmed, corresponding high-resolution imagery from the Formosat-5 satellite is acquired. This imagery is used to compare changes in image features at the disease outbreak site, confirming the detailed extent and area of disease occurrence. This process serves as the foundation for multi-dimensional and multi-scale satellite image plant detection.

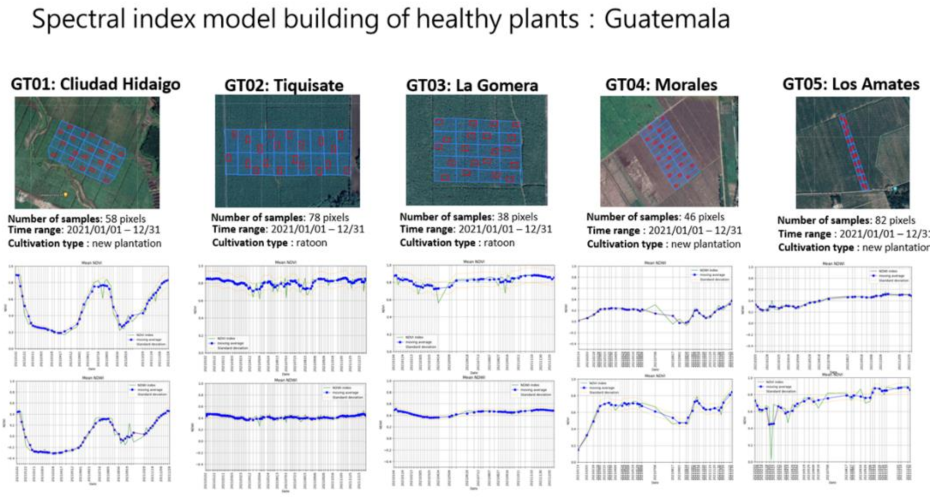


Figure 3. Building a statistical model for the time-based growth of healthy banana plants using spatial spectral indices (NDVI and NDWI) Gaussian distribution - A case study in Guatemalan fields

2.4 Image Detection Notification Reporting System

The plant disease detection model is currently fully established and operates according to the following procedure: 1. Historical farm data preview, 2. Generation of plant growth statistical models, and 3. Analysis and output of anomaly points. In the research, initial identification of abnormal and normal areas is done through historical image previews. Based on the initial assessment, normal areas are identified to construct plant growth statistical models. Once constructed, these models are applied to test locations to determine if they are abnormal.

Subsequently, notifying farmers of any anomalies is a crucial aspect of the system. Therefore, after determining anomalies in the Data Cube monitoring process, relevant anomaly information is output, including location and image and index results. This information is automatically imported into the Image Detection Notification Reporting System. Farmers can log into the system to check if there are any abnormal points on their farms. They can download location information maps to view the affected areas and report back through the system.

Farmers using the Image Detection Notification Reporting System can filter and query disease locations based on the date and farm. They can also download information such as images and coordinates. Using map information, they can visit and inspect the affected locations. Finally, farmers can take photos and provide descriptions of their findings, which are then stored in the database. For administrators, this system provides access to collected information. In addition to scheduling image detection and tracking progress in monitoring areas, the reported data can be used by users and disease control researchers for current situation assessment. It can also serve as a reference for subsequent image analysis work or system interpretation parameter adjustments (Figure 4).

Figure 4. Workflow and user interface for system management and monitoring control

3. MODEL VALIDATION

3.1 Central American Plant Disease Monitoring Exercise

To validate the monitoring model in this study, OIRSA conducted a large-scale plant disease prevention exercise in Central America in February 2023. This was achieved by simulating plant diseases through the application of herbicides. Subsequently, TASA established a satellite image monitoring model to confirm the simulated disease locations. Finally, disease notifications were issued by TASA, and local farmers were dispatched to the site to confirm the situation and take appropriate action.

3.1.1 Satellite Image Features: In early February 2023, OIRSA conducted herbicide spraying in the monitoring fields in Central America, resulting in the appearance of yellowing and withering of banana leaves. Therefore, using the plant disease monitoring model, we initially monitored changes in the observation fields periodically through Sentinel-2's natural color and near-infrared images (Figure 5). Starting from February 20, 2023, we observed bare features in the images. Additionally, through the calculation of NDVI and NDWI indices, we found a significant decrease in values in that area (Figure 6). As a result, we will proceed to perform further calculations for the health probability of that region.

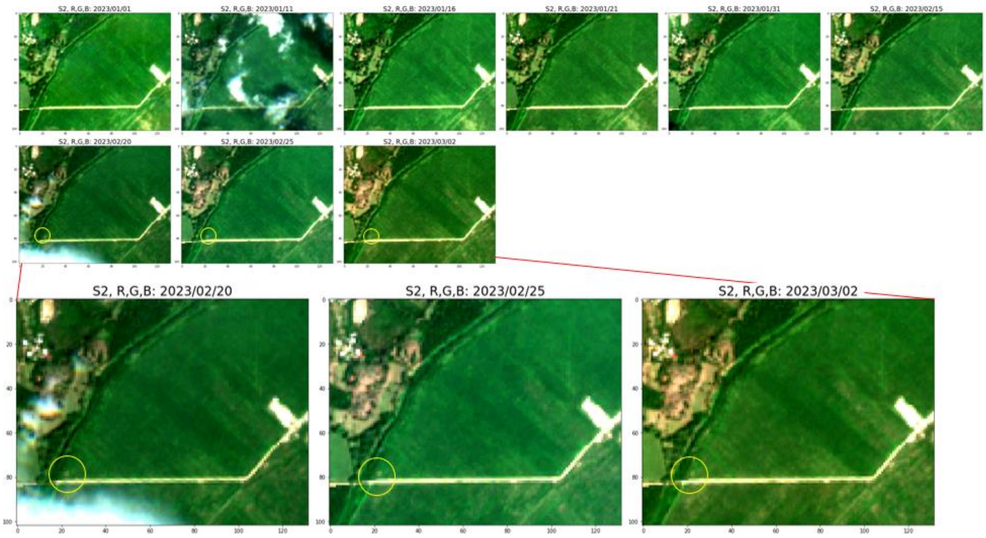
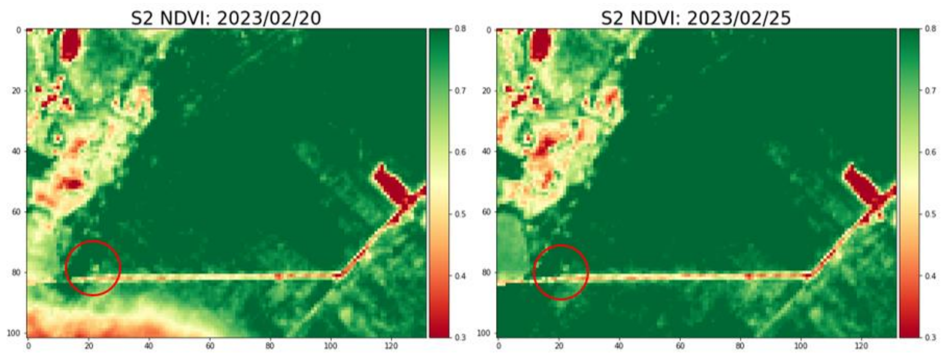


Figure 5. It appears that before the herbicide injection, this area exhibited distinct characteristics compared to the surrounding plants.



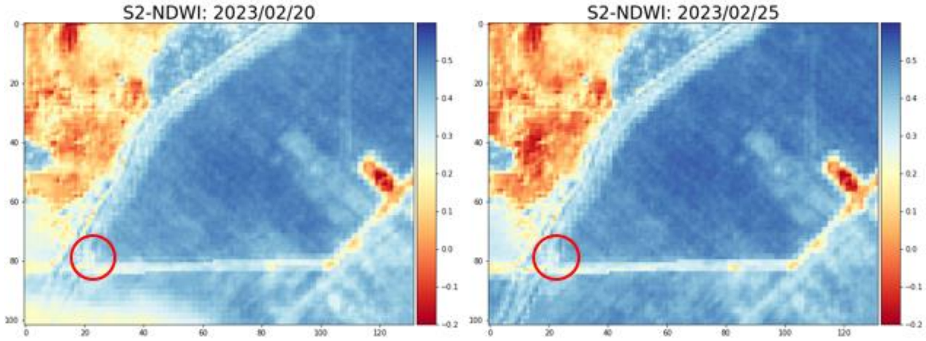


Figure 6. Through the calculation of NDVI and NDWI indices, we found a significant decrease in values in that area

3.1.2 Model Analysis Results: We have preliminarily confirmed the suspected herbicide spraying locations in the monitoring fields. Therefore, we aim to ensure the occurrence of plant disease in this area. I have established Gaussian distributions for the NDVI and NDWI health models in this region. Utilizing the spatial spectral index Gaussian distribution of healthy bananas as a temporal growth statistical model for healthy bananas, we calculate the health probability of banana plantations at the test location and determine whether their health status is abnormal. The results indicate that the health probability of banana plantations in the suspected herbicide spraying locations is below the 95% confidence interval. Therefore, there is a high likelihood that the growth of banana plantations in that area is relatively abnormal. This further confirms that the location has been subjected to herbicide spraying (Figure 7).

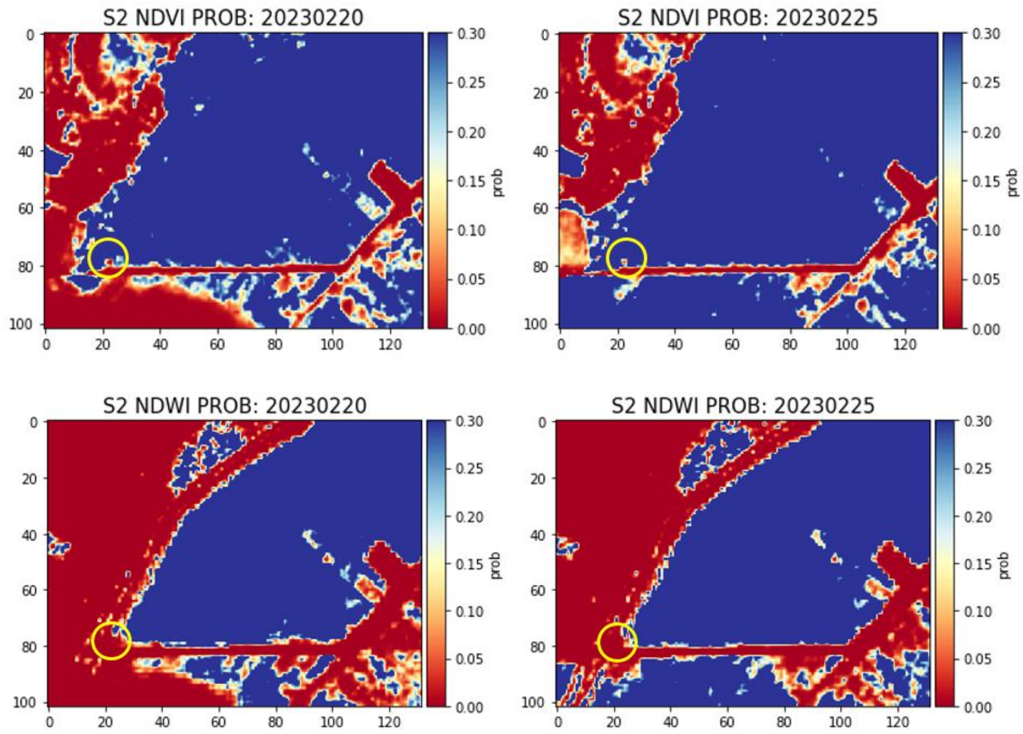
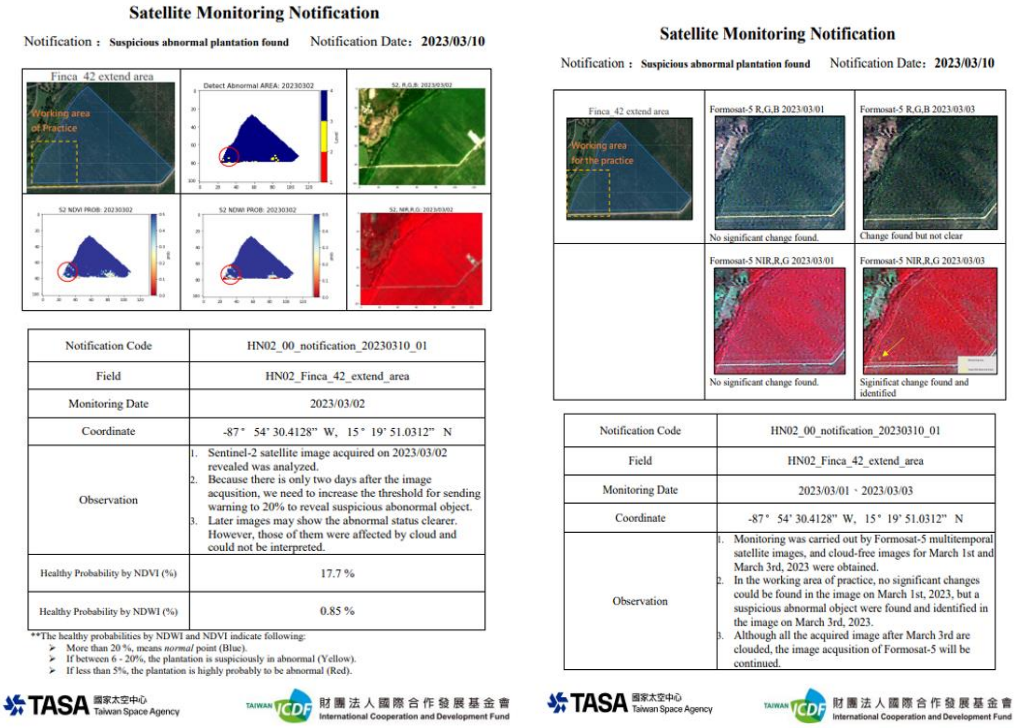


Figure 7. Through the calculation of NDVI and NDWI indices Gaussian distribution of healthy, we found a yellow location is below the 95% confidence interval.

3.1.3 Notification Results: Upon confirming the herbicide spraying location, TASA immediately accessed Formosat-5 satellite image data with high spatial resolution of 4 meters to inspect the status of the target area from a high-altitude perspective. We utilized surface bare features to digitize and label the target area. Finally, we issued a satellite monitoring notification report for on-site farmers to review. The report includes the statistical results obtained through the Sentinel-2 image model recognition and the visual spatial recognition results from Formosat-5 (Figure 8).



Notification Code	HN02_00_notification_20230310_01
Field	HN02_Finca_42_extend_area
Monitoring Date	2023/03/02
Coordinate	-87° 54' 30.4128" W, 15° 19' 51.0312" N
Observation	1. Sentinel-2 satellite image acquired on 2023/03/02 revealed was analyzed. 2. Because there is only two days after the image acqusition, we need to increase the threshold for sending warning to 20% to reveal suspicious abonormal object. 3. Later images may show the abnormal status clearer. However, those of them were affected by cloud and could not be interpreted.
Healthy Probability by NDVI (%)	17.7 %
Healthy Probability by NDWI (%)	0.85 %

**The healthy probabilities by NDWI and NDVI indicate following:
- More than 20 %, means *normal* point (Blue).
- If between 6 - 20%, the plantation is suspiciously in abnormal (Yellow).
- If less than 5%, the plantation is highly probably to be abnormal (Red).

Notification Code	HN02_00_notification_20230310_01
Field	HN02_Finca_42_extend_area
Monitoring Date	2023/03/01、2023/03/03
Coordinate	-87° 54' 30.4128" W, 15° 19' 51.0312" N
Observation	1. Monitoring was carried out by Formosat-5 multitemporal satellite images, and cloud-free images for March 1st and March 3rd, 2023 were obtained. 2. In the working area of practice, no significant changes could be found in the image on March 1st, 2023, but a suspicious abnormal object were found and identified in the image on March 3rd, 2023. 3. Although all the acquired image after March 3rd are clouded, the image acqusition of Formosat-5 will be continued.

Figure 7. The report includes the statistical results obtained through the Sentinel-2 image model recognition and the visual spatial recognition results from Formosat-5.

4. CONCLUSION

This project has currently implemented the establishment of a multi-temporal satellite image cloud storage and computing system in the Central American region using Data Cube, along with the collection of satellite imagery. Additionally, a planned and operationalized routine image acquisition and analysis process using Formosat-5 imagery has been established. Furthermore, an automated downloading and importing procedure for Sentinel-2 imagery from AWS as a data source has been completed. The International Cooperation and Development Foundation (TaiwanICDF) has provided 11 locations in Guatemala and 4 in Belize, with 20 monitoring zones planned for each location, resulting in a total area of 136.26 hectares. In this project, the Taiwan Space Agency (TASA) employed a uniform random sampling approach across the monitored banana areas to construct health models. The use of an averaging sampling process is expected to maintain the accuracy and stability of the health models, with rolling corrections applied when necessary with the most recent data. Finally, after a large-scale plant disease prevention exercise conducted by the International Regional Organization for Plant and Animal Health (Organismo Internacional Regional de Sanidad Agropecuaria, OIRSA) in Central America, the feasibility of large-scale plant disease monitoring using satellite resources has been comprehensively validated.

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