HR-SAGE: Harvest-Ready Sugarcane Assessment via GIS and Earth Observation

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***Abstract*— The unique and delicate growth pattern of sugarcane crop necessitates accurate monitoring and growth stage classification, particularly on harvest-ready sugarcane crops, for effective crop management, resource management, and yield maximization. This study introduces the HR-SAGE application (Harvest-Ready Sugarcane Assessment via GIS and Earth Observation), a web-based application designed to detect, visualize, and classify sugarcane crops into their four growth stages across the Philippines at 10m spatial resolution using the GEDI-Sentinel-2 global sugarcane map by Di Tommaso et al. and NDVI data from the Sentinel-2 dataset. The application utilizes Geospatial computation in identifying verified sugarcane pixels, vectorizing them into centroids, classifying them into growth stage depending on NDVI characteristics and cumulative tall canopy months (nTallMonths), and visualizing them in an interactive GIS map is done by the application using Google Earth Engine (GEE). The sugarcane pixel detection, the vectorization process, as well as the growth stage classification using NDVI and nTallmonths were validated and approved by agricultural engineering expert Dr. Moises Dorado of the College of Engineering and Agro-Industrial Technology, UPLB, with all of the methods being scientifically grounded. Results showing a great level of user satisfaction with the UI's simplicity and details were assessed using the System Usability Scale (SUS) and an in-depth qualitative and comparative survey. Expert review further attested to the scientific validity of the pixel-level detection, classification logic. The study proposes potential improvements in the future, such as processing cloud-covered images, using predictive models, and verifying the local fields with agriculture experts. HR-SAGE provides a scalable, user-friendly, and scientifically grounded solution to sugarcane growth monitoring in the Philippine sugarcane industry.**

***Index Terms*— HR-SAGE, GIS, Sentinel-2, GEDI-LiDAR, NDVI, GEE, nTallmonths, Centroid, SUS**

I. Introduction

A. Background of the Study

The cultivation of sugarcane crops is an integral part of the Philippines' economy, supplying national sugar, fertilizers, biofuel, animal feeds, and many more fundamental resources. It is imperative to have a deeper understanding of its distinctive growth behavior to facilitate its production and effectively meet the industry's demand. In a study by SRA in 2022, about PHP 76 billion of the Philippine economy was contributed by the sugarcane industry annually, with a current cultivation of 398,478 hectares. 57 percent of the aforementioned hectare are from Negros Island, 21 percent are from Mindanao, 11 percent from Luzon, 8 percent from Panay, and 3 percent from Eastern Visayas [1].

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Timely harvest scheduling is extremely crucial in preserving crop quality and maximizing yield. Harvesting them prematurely or overdue results in a significant loss in cane yield, poor juice quality, and issues in sugar recovery and milling [2]. Traditional harvest estimation practices are known to lack uniformity, suffer from inaccuracy, and are prone to human error, causing significant stakeholder loss. Identifying a sugarcane's phenological stage is proven to be quite a challenging task, especially on a district scale. Frequent on-site visits to assess the readiness of sugarcane farms for harvesting take too much valuable time that could otherwise be spent on more productive endeavors.

This study proposes the development of HR-SAGE or Harvest-Ready Sugarcane Assessment via GIS and Earth Observation application, an extension of the SiMFES application, combining Geographic Information System (GIS) mapping technology and high-resolution satellite imagery for assessing sugarcane growth stage and determining its readiness for harvest. HR-SAGE aims to provide a fully automated, cost-efficient solution for obtaining harvest-readiness information for the Philippine sugarcane industry, minimizing on-site visits and guaranteeing timely harvesting and maximized yield [3], [4].

B. Statement of the Problem

Traditional practices of determining sugarcane crop readiness to be harvested remain heavily dependent on frequent visits to the farms, which are inefficient and time-consuming, especially when the prediction of the harvest goes haywire in the actual timeline [5]. Cumulative wastage of time thereby leads to decreased productivity, resulting in a substantial loss of livelihood for the farmer, miller, and other stakeholders. Modern solutions are often such as data extraction from open-source platforms and manual visualization using GIS tools, require mastery and a deep learning curve to be used effectively. Furthermore, traditional identification of the sugarcane growth stage and harvest-readiness also reflects inconsistencies due to it being largely based on subjective visual judgments of farmers, which, at times, may not be accurate. With the sensitive growth pattern of the crop, such imprecision cannot be afforded.

C. Significance of the Study

The gravity of incorporating technology with agricultural practices grew larger and larger as modern farming approaches exhibited promising productivity enhancement, particularly with the introduction of remote sensing technology that utilizes ground reflectance in identifying the physical characteristics of objects, including crops [5]. The development of HR-SAGE will better serve the interests of the farmers and other stakeholders, as it uses a more streamlined, organized, and cost-effective method for monitoring the current growth stage of their sugarcane farms for potential harvest with a minimal learning curve to use. The on-site inspections of sugarcane farms will be significantly reduced, allowing the farmers to allocate more time to other tasks and guarantee a timely crop harvest. The precise visualization of satellite data automatically updated every 5 days facilitates more informed decisions for the allocation of resources by millers. Other stakeholders might realize general productivity and sustainability improvement within the sugarcane industry upon the application of HR-SAGE. With HR-SAGE, agricultural management will be effectively accomplished; maximum productivity and resource wastage will be avoided.

D. Objectives of the Study

The study aims to develop HR-SAGE, a satellite-based geospatial system for identifying harvest-ready sugarcane crops and classifying their growth stage with free and accessible tools. Specifically, this study aims to:

1) Implement verified crop masking techniques using satellite imagery to detect and distinguish sugarcane crops from other vegetation;
2) Develop a web-based GIS mapping tool integrating satellite imagery data for sugarcane pixel visualization and growth stage analysis;
3) Provide nationwide information about the sugarcane location and growth stage; and
4) Assess the application's usability and acceptability using SUS.

E. Scope and Limitations of the Study

This study will focus on developing and deploying HR-SAGE for farmers in sugarcane crop harvesting. The system features that will be developed will focus on addressing the concerns in identifying sugarcane crop locations and classifying them according to growth stage. Growth stage classification will make use of the NDVI vegetative index value and canopy structure. Finally, the study assumes full visibility of the planet in the satellite imagery data derivation.

The dataset and geographic information will be confined to the Philippine regions identified for the years 2022-2024. During its implementation period, user feedback and surveys will evaluate the application's effectiveness.

F. Date and Place of the Study

The study will be conducted at the Institute of Computer Science, College of Arts and Sciences, University of the Philippines, Los Baños, in the second (2nd) semester of the Academic Year 2024-2025.

II. Review of Related Literature

In recent years, the use of remote sensing and GIS-based technologies has grown in popularity within the agricultural sector, with their numerous practical applications, especially in monitoring crops. Sugarcane, being one of the few staple crops in the Philippines, has been subjected to numerous studies, utilizing innovative technologies in examining their unique growth stage and farming procedures to maximize their yield potential. The subsequent review of literature discusses the unique characteristics of each sugarcane growth stage while exploring various modern crop monitoring techniques, including spectral analysis, vegetative indices, and GIS mapping for more enhanced development of the HR-SAGE application in assessing sugarcane harvest-readiness, thereby fostering more efficient and sustainable crop management practices.

A. Growth Stages of Sugarcane

Sugarcane, like other vegetation, has distinct phenological stages that are essential to recognize to monitor and manage its growth effectively. Each stage exudes unique physiological characteristics corresponding to the crop's current growth stage.

Typically, a sugarcane growth stage is divided into four (4) stages, namely: the germination or early stage, the tillering stage, the grand growth stage, and the ripening and harvesting stage [6].

Growth Stage	**Remark Crop Color**	**Color**
Germination	The crop is primarily dependent on the sett roots. Heavily influenced by soil, temperature, and moisture level.	Light Green
Tillering	Multiple shoots (tillers) are formed. Stress is fatal for the crop.	Bright Green
Grand Growth	The stem elongates rapidly. High photosynthetic activity.	Deep Green
Ripening and Harvesting	This is when the senescence outsets and the stalks amass sucrose.	Yellowish Green\Yellowish Brown

TABLE I: Sugarcane Growth Stage and Physical Characteristics

Table I depicts the stages of growth that sugarcane crops undergo with their corresponding characteristics and crop color. It can be observed that the colors are very distinct in every growth stage, ranging from light green to yellowish brown.

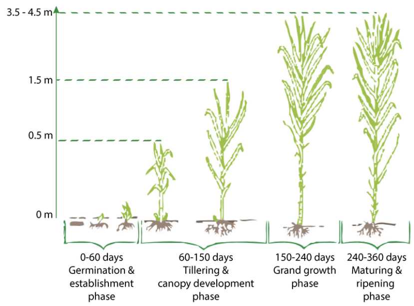

Fig. 1: Phenological phases of sugarcane and their corresponding time frames, as well as indicative heights and plant geometries. Adapted and modified from NaanDanJain [6].

Figure 1 provides a height comparison of sugarcane as it undergoes its four growth stages. A careful examination of Figure 1 illustrates the significant height growth, ostensibly its peak, exhibited by the sugarcane starting from its grand growth phase to its ripening phase, reaching a height of 3.5 to 4.5 meters that lasts for about 150 to 240 days and 240-360 days, respectively.

Identifying these stages with their respective physical characteristics and growth behavior is not only pivotal in proper resource allocation but also a significant component of an accurate growth stage distinction of sugarcane, assessing its harvest readiness, and pushing more cost-effective and sustainable farming practices in the sugarcane industry [7], [8].

B. Spectral Analysis for Sugarcane

The spectral signature is a function of wavelength, which is the ratio of reflected radiation energy to incident radiation energy on an object. Spectral analysis is a popular remote sensing technique that uses distinctive reflectance properties of crops across specific wavelengths in determining and differentiating specific vegetation types. The spectral signatures emitted provide pivotal qualitative information in classifying remotely sensed data, and this approach has been proven to be effective in distinguishing sugarcane from other vegetation and its four growth stages classification [9], [10].

Sugarcane has been known to exhibit unique spectral signatures that largely depend on the phenological stage the crop is currently in. As the crop develops, the change in its physiological and biochemical properties results in variability of the spectral signatures and the intensity of their pronunciation. Plotting the spectral signature of sugarcane, its growth stages start to be separable at the NIR (Near Infrared) spectrum, around 750 to 850 nanometers (nm) [9].

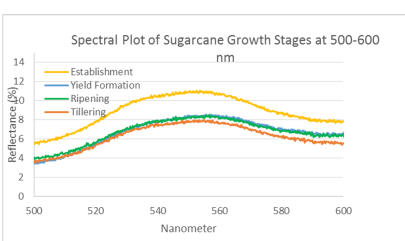

Fig. 2: Spectral Plot of Sugarcane Growth Stages at 500 to 600 nm [9].

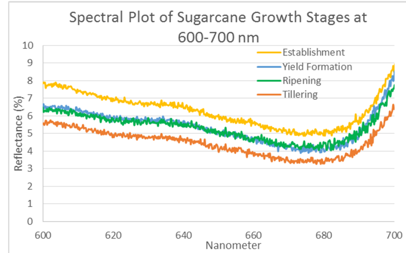

Fig. 3: Spectral Plot of Sugarcane Growth Stages at 600 to 700 nm [9].

The observations in the sugarcane spectral signature at 500600 nm and 600700 nm, respectively, are displayed in Figures 2 and 3 above. The Establishment and Tillering stages are clearly distinct in the green and red spectrum, respectively, at 500600 nm and 600700 nm, as seen in both figures. On the other hand, it is also evident that the Yield Formation and Ripening stages are closely related.

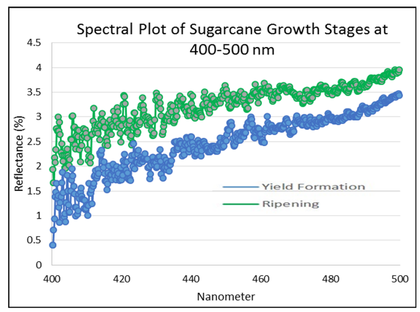

Fig. 4: Spectral Plot of Sugarcane Growth Stages at 400 to 500 nm [9].

A closer examination of the 400 to 500 nm spectral signature, as shown in Figure 4, describes how the Yield Formation and Ripening stages are, indeed, distinguishable.

Hence, spectral analysis, particularly in the 400-700 nm for the visible and 750-850 nm for the NIR, is a recommended method not only for distinguishing sugarcane from other surrounding vegetation but also for identifying the current growth stage of the crop that is pivotal in determining its viability for harvesting [10].

C. Vegetation Indices for Crop Monitoring

To highlight the significant characteristics of vegetation, including its health, biomass, and density, a vegetation index (VI) is used. A vegetation index is a mathematical transformation of the spectral reflectance data extracted from various bands of satellite imagery [11]. VIs are specially engineered to precisely isolate the vegetation signal by diminishing external complicating factors such as moisture content and environmental effects.

In the context of remote sensing and sugarcane crop monitoring, the most preferred index would be the Normalized Difference Vegetation Index or NDVI. It makes use of the combined radiation ratio of the near-infrared band (NIR) and red band (R), which are the two main bands where the sugarcane is explicitly distinguishable in our previous discussion about spectral signature [11]. NIR light is reflected in healthy vegetation while chlorophyll absorbs red light.

The NDVI is computed with the following formula [11]:

$$\text{NDVI} = \frac{NIR - R}{NIR + R} \tag{1}$$

With these, prompted by the values to be obtained in the spectral analysis of satellite imagery, the growth stages of a sugarcane crop can be further distinguished.

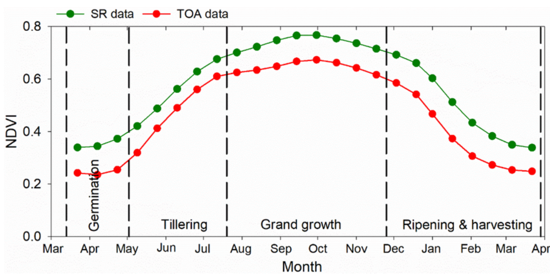

Fig. 5: Temporal Patterns of NDVI (standard NDVI curves) and growing stages for sugarcane in China for both SR and TOA data [11].

Figure 5 further expounds the NDVI with mapping of values to months across the different growth stages of sugarcane crops by comparing the NDVI temporal patterns of Surface Reflectance (SR) and Top of Atmosphere Reflectance (TOA) conducted in sugarcane fields in China. Figure 5 illustrates a bell-shaped graph, indicating a rising, then descending trend in its NDVI. Comparing the two reflectances used in the study, it describes the same, and almost identical pattern and behavior of values, with a slight difference between the two reflectances, enhancing the credibility of NDVI as an indicator of its growth stage [9].

Growth Stage	**NDVI Value Behavior**	**NDVI Value Range**
Germination or Early Stage	Low NDVI	0.25-0.34
Tillering	NDVI increasing quickly	0.35-0.54
Grand Growth	NDVI is reaching its peak	0.55-1.00
Ripening and Harvesting	NDVI sharply decreasing	0.55-0.7

TABLE II: Sugarcane Growth Stage and NDVI Value Behavior

Table II describes the sugarcane and its growth stages with their respective NDVI behavior and value range. The crop is observed to have a gradually increasing value of NDVI from 0.25 in its germination stage up to 1.00 when it reaches its grand growth stage. As it approaches its ripening and harvesting stage, its NDVI value starts to decrease, showcasing a decaying growth trend [12].

All of these further solidify the viability of using vegetation indices in generating precise and reliable predictions for sugarcane growth monitoring.

D. Sugarcane Global Crop Mapping

Di Tommaso et al.'s study (2024) illustrates an important step to improve the global crop mapping, including sugarcane, by merging NASA's GEDI lidar observations and high spatial resolution Sentinel-2 satellite-based images. This fusion allowed them to create a 10-meter global map of sugarcane occurrence in 13 major producing countries, including the Philippines. The study utilizes GEDI vertical canopy structure to distinguish sugarcane from other vegetation, particularly its tallness frequency within a year (referred to as nTallmonths in the data), and Sentinel-2 time series for temporal dynamics. Sugarcane crops that exhibited an NDVI value greater than 0.5, or having a height of at least 2 meters, are classified as tall [13]. As discussed in our previous literature about sugarcane phenological stages, this height is achieved by the crop as it transitions from tillering to grand growth and ripening stage, or from 1.5 meters to 3.5-4.5 meters, respectively [6]. Hence, a sugarcane crop is classified as tall when it is under its grand growth stage and ripening stage, which has an nTallmonths frequency ranging from 4 to 7 and 7 to 11, respectively. To achieve the best accuracy, the study is validated via field data and by cross-reviewing it with other crop masks and government statistics [13].

HR-SAGE aims to extend this model by assigning phenological stages to these detected pixels using the NDVI vegetation index. Utilizing the 10m sugarcane mask by Tommaso et al. [13], HR-SAGE restricts its stage classification and visualization attempts to the significant locations where sugarcane is found, maximizing accuracy and reducing unnecessary computational and resource burden. The global GEDI-Sentinel sugarcane product is crucial in HR-SAGE as a credibility reference for its monitoring system.

The prior studies demonstrate the importance of sugarcane phenology, remote sensing, spectral analysis, and GEDI-2 and Sentinel-2 datasets in monitoring sugarcane crops with their recent prevalence in modern agricultural activities. Examining the distinctive characteristics and vegetation indices extracted with these techniques shows an enhanced accuracy in assessing sugarcane growth stage, consequently, its harvest readiness when integrated with remote sensing technologies. This underscores the significance of developing HR-SAGE, which potentially provides a more streamlined sugarcane monitoring system by providing users with fully automated information on the sugarcane growth stage, leading to higher overall efficiency and productivity in farming.

III. Materials and Methods

This section outlines the materials and methods used in the development of the app Harvest-Ready Sugarcane Assessment via GIS and Earth Observation (HR-SAGE). The methodology includes the development tools, user types, pages, functionalities, architecture design, research design and implementation, use-case diagram, project scheduling, layout of pages, and testing and evaluation of the system. HR-SAGE aims to assist farmers, millers, and agricultural experts around the Philippines with a more effective harvest-readiness assessment and production management.

A. Development Tools

HR-SAGE will be developed in a modern computer setup with the following specifications:

- **Operating System:** Windows 10 64-bit.
- **Processor:** 11th Gen Intel(R) Core(TM) i5-11400H @2.70GHz 2.69 GHz
- **Memory:** 16 GB DDR4

The tech stack and environment that will be utilized for the development of the full-stack system are as follows:

1) Development Environment
   - **Visual Studio Code**
     A streamlined code editor for development operations in the system, including task running, debugging, and version control.
2) Dataset
   - **Sentinel-2**
     Sentinel-2 is a multi-spectral imagery dataset provided by the European Space Agency (ESA), primarily used for agricultural purposes like crop monitoring, to be extracted on Google Earth Engine (GEE) to identify sugarcane crops. This will be the dataset that will be primarily used and manipulated to identify the sugarcane crops remotely. HR-SAGE will make use of the red (665 nm) and the near-infrared band (842 nm) for the calculation of the crops' normalized difference vegetation index (NDVI) [17].
   - **GEDI(LiDAR)-Sentinel-2 Sugarcane Map**
     GEDI-Sentinel-2 is a 10-meter resolution global dataset offered by Di Tommaso et al. (2024), combining Sentinel-2 satellite imagery with Global Ecosystem Dynamics Investigation (GEDI) lidar data used for an accurate sugarcane mapping using a combination of structural and spectral crop features [13], [14]. This dataset will be primarily used as a sugarcane mask reference to limit the NDVI analysis to identified sugarcane pixels in the Philippines.
   - **ESA World Cover + GLAD Cropland Mask**
     The system will make use of a combination of the ESA World Cover and GLAD cropland mask provided by the European Space Agency (ESA) and the University of Maryland, respectively. The ESA World Cover dataset provides information regarding land type distinction, while the GLAD cropland mask offers high-resolution cropland extent mapping data [15], [16]. HR-SAGE will be used to restrict sugarcane growth detection and analysis to cropland areas, avoiding any region where sugarcane cannot thrive.
3) Data Extraction and Analysis
   - **Google Earth Engine (GEE)**
     Google Earth Engine, or GEE, is an online cloud-based geospatial analysis platform by Google that enables analysis of vast amounts of satellite imagery, supports classification, change detection, and time-series analysis. [17]. In this study, GEE will be used to perform geospatial tasks such as filtering, cropland masking, NDVI calculation, point detection, and export of data.
   - **Python**
     Python is a high-level object-oriented programming language that will be the base language for developing machine learning models to classify sugarcane fields, for scripting, and workflow automation. The system will use its latest version 3.11.
     - **Earth Engine Python API**
       Earth Engine Python API is a Python library used to integrate functionalities from GEE.
     - **Flask API**
       Flask API is a Python web framework utilized in building the system's backend, handling data fetching, processing, intelligent classification of sugarcane growth stages, and transporting data to the frontend.
   - **GitHub Workflow**
     GitHub Workflow is a free automated service for processing jobs by GitHub that will be used to for the systems cron job to automatically execute a periodical triggering of the GEE script for geospatial data extraction, including point location, tall months, and NDVI, which are to be exported in the system in a CSV format with an interval of 5 days as per Copernicus twin satellite revisit frequency at the equator [14].
4) Cloud Storage Services
   - **Google Drive**
     Google Drive is a cloud storage service by Google that will be used to temporarily store the exported CSVs from Google Earth Engine, containing geospatial data for HR-SAGE.
5) User Interface
   - **ReactJS**
     ReactJS is a frontend framework that will be used to develop the base frontend web application.
   - **Leaflet**
     Leaflet is a web-based scripting library to be used for tile-based web mapping spanning across the Philippines for sugarcane point location visualization.
   - **Tailwind CSS**
     Tailwind CSS is a CSS framework that incorporates pre-designed classes used for improving UI and UX style and features.

B. Architecture Design

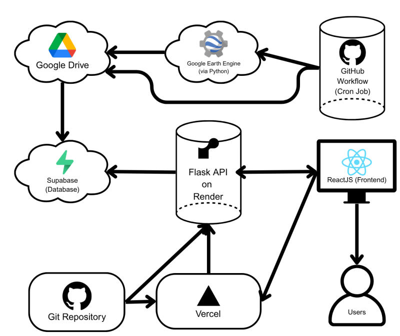

Fig. 6: HR-SAGEs web architecture design.

Figure 6 describes HR-SAGEs web architecture design and its respective technologies, comprising the full-stack system including the data extraction (Google Earth Engine triggered by GitHub Workflow), database (Supabase), backend (Flask API), cloud storage (Google Drive), frontend (ReactJS), deployment (Vercel, Render, and GitHub Repository), and the users. Figure 6 further illustrates the system component interaction and data flow in the system's deployment.

C. Research Design and Implementation

The HR-SAGE adopts an experimental development design in the implementation and evaluation of the system [18]. The system utilizes satellite imagery and web-based development principles in designing a streamlined platform for sugarcane detection and classification. To ensure HR-SAGE's usability and operational effectiveness, a set of prototyping, iterative testing, and user feedback assessments will be conducted.

HR-SAGE will be implemented with the following steps:

1) Data Collection and Processing
   - Satellite imagery and geospatial data, including approximate locations, crop structure (tallness) frequency in a month, and spectral bands, will be collected from Sentinel-2 and LiDAR datasets via Google Earth Engine for the year 2024.
   - Integrate the GEDI-Sentinel-2 Sugarcane Map dataset from the EESD project as an additional layer of reference in verifying the detection of sugarcane.
2) Sugarcane Detection and Vectorization using GEE Script
   - A script will be developed in Google Earth Engine, performing the following tasks:
     – Implement cloud filtering and cropland masking for the satellite imagery.
     – Detect and identify sugarcane pixels and temporal index values using GEDI-Sentinel-2 data.
     – Fetch the band values and calculate the NDVI values per detected sugarcane pixel.
   - For the conversion of satellite data to the system's data visualization provided in Di Tommaso et al.'s study [16] and NDVI value calculation, the following steps will be executed.
     a) Fetch raster images restricted to the Philippine tiles.
     b) Merge into one raster image.
     c) Apply a sugarcane mask to retain pixels labeled as sugarcane.
     d) Convert a raster image to a vector image.
     e) Convert the vector into a polygon.
     f) Determine the centroid of the polygon and use it as the location identifier of the sugarcane using its latitude and longitude.
     g) Fetch NDVI from the determined sugarcane pixel locations.
   - The scripts will be triggered every 5 days using GitHub Workflow, exporting the resulting data of each detected crop's latitude, longitude, height, NDVI, and growth stage in a CSV file in Google Drive and exported to Supabase.
3) Backend Development
   - The backend will be composed of the Flask API that performs the following tasks:
     – Automatically fetch from Supabase.
     – Parse and preprocess the data.
     – Classify the growth stage of the detected sugarcane based on crop tallness in a month and empirical NDVI thresholds.
     – Format the resulting data in a JSON string to be exported in the frontend.
4) Frontend Development
   - The frontend will be composed of ReactJS in combination with TailwindCSS styling. The frontend will require the following:
     – Development of the home page containing customized information for the users.
     – Development of the About Us page containing the developer's details.
     – Development of the Check Harvest page containing the Leaflet interactive map, visualization of the sugarcane pixels in a 25m x 25m pixel size (equivalent to a real land area) and their respective growth stage, toggle-based visual filtering, location searching, and map printing features.
   - Improve user interface (UI) and user experience (UX) using Tailwind CSS styling, focusing on ease of use and responsiveness.
5) Participant Drafting, Feedback Survey, and Assessment
   - After the initial deployment of HR-SAGE, 15 participants comprising college students in any degree program will be selected to test the system.
   - After testing, the participants will be administered a System Usability Scale composed of a 10-item standard items answerable via a 5-point Likert scale.
   - Feedback will be collected to analyze the system's usability, functionality, and user confidence in using the system.
6) Final Deployment
   - Based on the results of testing and survey, suggested features and improvements, as well as identified issues, will be addressed and implemented in the system so that the participant drafting, feedback survey, and assessment can be iteratively executed until a satisfactory result in the SUS is achieved.
   - The system will be deployed over the internet using Render and Vercel for public use.

D. User Types

The HR-SAGE system caters to all types of users engaging in sugarcane detection and growth stage analysis. Specifically, this system would be of great benefit to sugarcane farmers, agricultural experts, and millers. The user is equipped with functionalities and roles that suit his/her requirements in using the system.

E. Pages and Functionalities

To cater to all types of users, the system will be developed as a web-based application with the following pages and functionalities:

- Home Page\Dashboard
  The homepage is a simple dashboard that displays news and relevant information on sugarcane farming practices in the industry, comprised of cards that can be expanded for a clearer viewing to keep the users updated.
- 'Check Harvest' Page
  - Sugarcane Map
    The Leaflet map is the default map displayed after navigating to the page is the Regional Map with a zoom-in feature and information indicating the number of days until the next geospatial data update, which will graphically depict a sugarcane-growing region. The user can then select a region to which it will zoom in for a closer look at the field map. The map's tile set can also be changed via the drop-down menu. A map summary can also be generated using the Download PDF button.
  - Search Location
    Users can search for a particular location to which the map will redirect and frame to the location's center.
  - Legend
    The Legend panel contains buttons corresponding to a particular growth stage that the user can click to toggle which sugarcane pixels under a particular stage will be displayed on the map.
- 'About Us' Page The About Us page contains useful information regarding HR-SAGE and its developers.

F. Project Scheduling

Figure 7 below shows the schedule for the development of the HR-SAGE system using a GANTT chart. The project development spans the entire second (2nd) semester for the academic year 2024-2025.

Task	Month					
	1	2	3	4	5	6
Literature Review						
Data Collection						
Design of System (GEE Script and Cloud Storage Setting Up)						
Sugarcane Detection and NDVI Classification Development						
Backend Development (API)						
Frontend Development (UI/UX)						
Testing and Evaluation						
Final Deployment						

Fig. 7: GANTT Chart for the development of HR-SAGE

G. Layout of Pages

The following figures - Figures 8, 9, and 10 are high-fidelity wireframes of the layouts of the system with its different instances to better describe the system's appearance from a user's perspective.

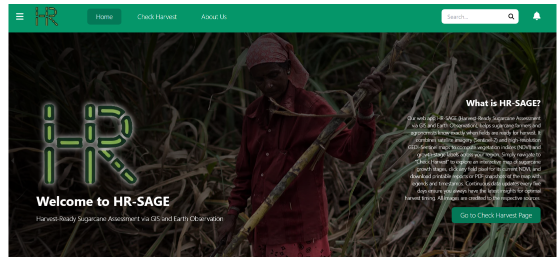

Fig. 8: Home Page\Dashboard Page of HR-SAGE

Figure 8 is the dashboard to which the users will be redirected initially after opening the application. The page is very straightforward, displaying news, announcements, and educational blogs that farmers can examine to stay updated.

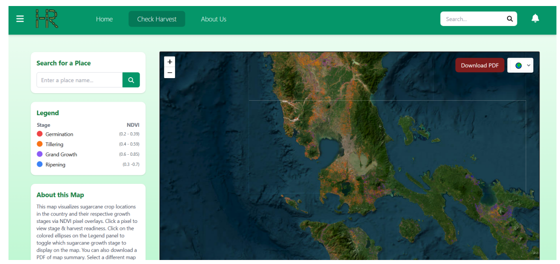

Fig. 9: 'Check Harvest' Page of HR-SAGE

Figure 9 shows the Check Harvest page of HR-SAGE. On the right panel, the default map displayed after navigating to the page is the Regional Map. The user can then select a region to which it will zoom in for a closer look at the field map. The left panel includes a column of cards comprised of the four (4) growth stages classification of sugarcane, containing information about the growth stage and their respective NDVIs. The stages can be toggled to select which crops under a particular stage will be displayed. A search functionality is also provided to locate particular locations in the Philippines.

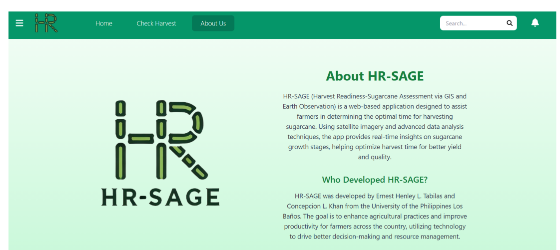

Fig. 10: 'About Us' Page of HR-SAGE

Figure 10 shows the About Us page containing basic information about HR-SAGE and its developers and co-developers.

H. Testing and Evaluation

HR-SAGE will be tested through a feedback survey that will be given to 15 selected participants, composed of college students in any degree, after they test the system. To examine the usability and performance of the system, the System Usability Scale (SUS) that John Brooke proposed [19] in answering the following questions:

1) I think that I would like to use HR-SAGE frequently.
2) I found HR-SAGE unnecessarily complex.
3) I thought HR-SAGE was easy to use.
4) I think that I would need the support of a technical person to use HR-SAGE.
5) I found the various functions in HR-SAGE were well integrated.
6) I thought there was too much inconsistency in HR-SAGE.
7) I would imagine that most people would learn to use HR-SAGE very quickly.
8) I found HR-SAGE very cumbersome to use.
9) I felt very confident using HR-SAGE.
10) I needed to learn a lot of things before I could get going with HR-SAGE.

Responses in the SUS will be used to assess the system's ease of use, functionality, and user confidence as guidelines for future improvements.

IV. Results and Discussion

This section discusses the results of the testing and evaluations imposed and their implications in the study.

A. Expert Validation

A meeting was conducted on May 14, 2025, with the agricultural engineering expert, Professor Moises Dorado, a Professor in the College of Engineering and Agro-Industrial Technology, UPLB, and leading the project Community-Level SARAi Enhanced Agricultural Monitoring System (CL-SEAMS), responsible for providing specialized crop advisories [20]. The meeting involves a thorough demonstration of HR-SAGE, testing its features and underscoring its method of implementation, particularly in the automated extraction and processing of satellite imagery data. The expert affirmed the following strengths of the system. First, the use of Di Tommaso et al.'s 10m resolution GEDI-Sentinel dataset as the sugarcane baseline ensures scientifically grounded sugarcane pixel detections. Second, the process of vectorization and centroid extraction from raster sugarcane pixels is justified and accurate, with little spatial distortion due to the resolution. Lastly, the NDVI and nTallmonths classification thresholds align with documented patterns from peer-reviewed publications [6], [11], [12], reflecting logical segmentation across Germination, Tillering, Grand Growth, and Ripening stages. All of these validate the data fetching, processing, and logical classification of HR-SAGE as scientifically grounded and peer-reviewed, as well as its usability in a large-scale deployment in the sugarcane industry.

B. Usability Assessment

To assess HR-SAGE's usability, the System Usability Scale (SUS) was administered to 15 selected college students of varying degree programs.

Ref	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Total
R1	4	2	4	2	4	1	4	1	5	1	85
R2	4	1	5	1	5	2	5	1	5	1	95
R3	4	2	4	4	4	2	4	2	4	2	70
R4	4	2	5	2	5	1	5	1	5	1	92.5
R5	4	1	5	1	4	1	5	1	5	1	95
R6	5	1	4	1	5	1	4	1	4	1	92.5
R7	4	2	5	1	4	1	5	1	5	1	92.5
R8	3	5	1	5	1	4	1	5	5	5	17.5
R9	4	3	5	2	4	2	5	2	4	2	77.5
R10	4	1	5	1	4	2	3	1	5	2	85
R11	3	1	5	1	4	2	5	1	5	1	90
R12	5	2	5	1	5	2	4	1	5	2	90
R13	4	1	5	2	5	1	4	2	4	2	85
R14	5	1	5	1	5	1	5	1	5	1	100
R15	4	1	4	4	4	1	4	1	4	2	77.5

TABLE III: SUS Score Summary

Table III summarizes the SUS score findings, with each row corresponding to a participant with their respective Likert scale score per question. The average SUS score of the survey was 83, with an equivalent grade of A, categorized as Excellent in accordance with standard SUS interpretation thresholds [19]. The satisfactory score implies a high level of perceived usability of the HR-SAGE application. Participants reported ease-of-use in the user interface, with particular appreciation for its pixel-level accurate sugarcane mapping. The relatively high SUS score supports the usability and effectiveness of the application when used at a production level [19].

C. Qualitative Feedback Analysis

In order to gain deeper insights into the application's usability, participants were also asked two open-ended questions to describe (a) what they liked most and (b) what they liked least about HR-SAGE.

The majority of the participants responded with the application's ease of use and easy navigation, with no complex menus and elements, requiring a minimal learning curve to use. Participants also underscored specific features they found handy, including the pixel-accurate visualization of sugarcane points, the useful information included in popups, the downloadable summary, its accessibility in smartphone browsers, and the pre-fetching of data for a faster layer rendering.

While the majority of the responses are positive, some users expressed concerns with regard to the loading performance, particularly its slow loading times when visualizing a large set of sugarcane pixels. This clearly indicates a room for improvement in optimizing the loading and rendering of spatial data in the application, especially in different unideal instances such as slow internet connectivity and concurrent user queries. Overall, the qualitative feedback substantiates the design choices made for HR-SAGE, with keywords including simplicity, straightforwardness, and easy-to-use made by the participants. These insights provide a road map for iterative improvements, particularly on performance optimization.

D. Visual Accuracy Validation

To assess spatial accuracy, two validation questions answerable by yes or no were also asked to the participants, comparing the pixel outputs of HR-SAGEs sugarcane map with the GEDI-Sentinel-2 global sugarcane dataset [13], visualized using GEE (See Figures 11 and 12 below).

Fig. 11: Visualization of Di Tommaso et al.'s dataset in Palauan, Philippines, using GEE [13].

Figure 11 displays a broad perspective of the sugarcane pixels output provided by Di Tommaso et al.'s dataset, zoomed in on Palauan, Philippines [16] using the 'addLayer' functionality of GEE.

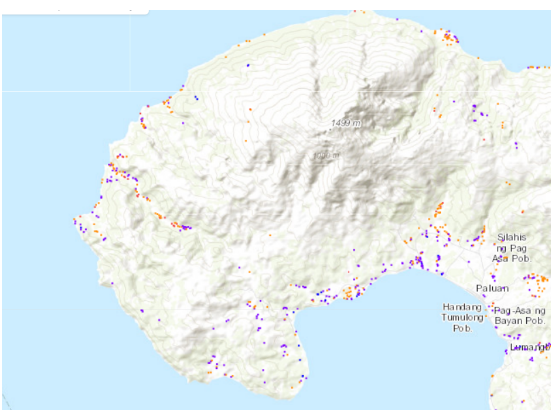

Fig. 12: Visualization of Di Tommaso et al.'s dataset in Palauan, Philippines, using GEE [13].

Figure 12 navigates to the same location as Figure 11, displaying sugarcane pixels but in vectorized and centroid-extracted form. Comparing Figure 11 and Figure 12, the varying approach of the two visualizations yields visually identical results, with each point found in Figure 11 corresponding to a point in Figure 12 found in the same location, with a slight difference in pixel size as HR-SAGE opts for a 25m x 25m (equivalent to real land area) pixel coverage display for usability and visibility, as compared to Di Tommaso et al.'s 10m x 10m original pixel size.

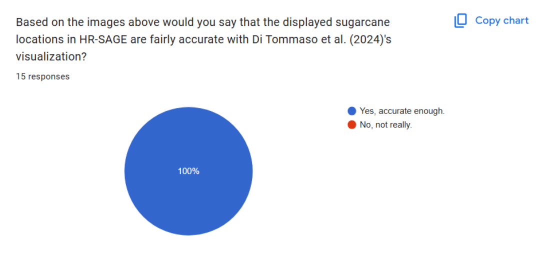

Fig. 13: Pie chart of the participants' response to the spatial data accuracy question in the survey.

Figure 13 illustrates a pie chart of the summary of the participants' responses to the spatial data accuracy question in the survey. Examining the chart, over 100% of participants attested that the HR-SAGE pixel locations matched Di Tommaso et al.'s dataset. This implies that the export and centroid logic employed in GEE maintains excellent geographic fidelity, which is vital in conveying correct information to the users.

V. Conclusions

The HR-SAGE application promises a more effective way of sugarcane detection and growth stage classification in the Philippines, utilizing a scientifically grounded approach to integrating Sentinel-2 and GEDI-LiDAR data with remote sensing methods. Employing an accurate pixel-based extraction, vectorization, and NDVI-based and canopy height-based classification, HR-SAGE can accurately detect and visualize sugarcane growth phases in an interactive, streamlined web platform. The methods used in sugarcane pixel detection, the vectorization and centroid extraction process, as well as the growth stage classification, are all validated and approved by agricultural engineering expert Dr. Moises Dorado of the College of Engineering and Agro-Industrial Technology, UPLB. Usability testing using the SUS indicated high user satisfaction, and participant surveys, directly compared with published datasets, further validated by expert reviews, underpin the value of the geospatial and analytical accuracy and precision of the system. The application is praised for its simplicity and small learning curve, while it is criticized for its slow rendering of data.

The integration of satellite imagery for pixel-accurate mapping, along with NDVI trends and nTallMonths in growth stage classification, provides meaningful insights that stakeholders such as researchers, policy-makers, and mill operators can utilize in facilitating better resource management and harvest planning for sugarcane, reducing frequent on-site visits, resource wastage, and maximizing yield. The method is heavily rooted in well-grounded remote sensing technology and literature crop phenology, increasing the credibility and usability of the HR-SAGE in the academic and applied agriculture sector.

VI. Recommendations

To enhance HR-SAGE scalability and accuracy, future researchers can explore the following suggestions:

1) Develop a mechanism to handle instances of cloud-covered regions during the satellite scanning of the planet

to improve accuracy, temporal data reliability, and avoid data gaps.

2) Integrate predictive and machine learning models to estimate the trend of NDVI values during cloudy periods to maintain data continuity under suboptimal conditions.
3) Develop a feature that allows authorized data contributions from agricultural experts and field technicians who regularly do field visits and monitoring to validate data derived from the satellite.
4) Restrict data derivation and visualization to specific established sugarcane producing regions and mill districts for better performance.
5) Optimize the mobile application view for mobile usability, allowing portability of the application.
6) Add locale information on sugarcane pixel popups.

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VIII. Conflict of Interest

The authors declare no conflict of interest.

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