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Research Article

MangoTayo!: A Sustainable Smart Agriculture Model for Mango Industry Upliftment in Davao del Sur, Philippines

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ABSTRACT

Mango production in the Philippines ranked seventh globally, producing high-quality mangoes and supplying different countries. However, from 2000 to 2020, the Philippine mango sector saw a steady reduction in all industry performance metrics, such as production volume, productive area, yield per unit area, and yield per tree. Furthermore, the export of mangoes is not doing as well as in earlier decades. Other problems encountered by many farmers specifically small-scale farmers are lack of pest control and nutrient management, poor induction and flowering intensity, the lack of farm-to-market roads, and low farm-gate prices. Responding to these issues, the Mango Tayo! Program developed an AI-based Smart application for mango production management, utilizing cutting-edge technologies in smart agriculture. Thus, community engagement and activities were conducted to capacitate the women and men mango growers and contractors in Digos City using the developed technology. The program was found to be successful in achieving its objectives—enabling the community partners to use cutting-edge technology in farming.

Keywords: mango, artificial intelligence, iot, smart agriculture, community extension.

INTRODUCTION

Understanding mango physiology and orchard maintenance is necessary for the effective commercial cultivation of mangoes, which will attain fruit quality and commercial yield. To guarantee fruit quality and benefit growers, consumers, and the environment, a set of guidelines known as Good Agricultural Practices, or GAPs, has been established [1]. Mango production in the Philippines ranked seventh globally, producing high-quality mangoes and supplying different countries. However, from 2000 to 2020, the Philippine mango sector saw a steady reduction in all industry performance metrics, such as production volume, productive area, yield per unit area, and yield per tree. Furthermore, the export of mangoes is not doing as well as in earlier decades. In 2020, the sector contributed 1.95% to the major industry and recorded a gross value addition of Php 35.520 billion, making it the third most exported fruit crop in the Philippines despite this [2]. Moreover, as stated by the Philippine National Statistics, there was a decline in yield; a difference of 5.8 percent from 27.0 thousand metric tons produced from October to December 2021 down to 25.47 thousand metric tons of the same period in 2022. Other problems encountered by many farmers specifically small-scale farmers are lack of pest control and nutrient management, poor induction and flowering intensity, the lack of farm-to-market roads, and low farm-gate prices.

The 2023 Agenda for Sustainable Development aims to address the Zero-hunger wherein it talks about supporting sustainable agriculture and empowering small-scale farmers, to increase agricultural production, improve the global supply chain, reduce food losses and waste, and ensure that all people who are hungry or malnourished have access to nutritious food. In addition, the Philippine Development Plan for 2040 specifically on agriculture aims to adopt improved technology e.g., mobile platforms and channels will be encouraged for marketing, payment, and product delivery and the use of modern technology and better information systems [3]. Furthermore, the Davao Region's Research Agenda prioritizes developing, testing, and evaluating new and improved farming technologies; Science and Technology-based production and processing systems.

Thus, the province of Davao del Sur continued its support of the mango industry. Data from the Office of the Provincial Agriculturist (OPAG) in 2021 showed that 10, 525.78 hectares of mango orchards were distributed to all the municipalities and the city of Digos. Malalag led the province in the mango industry, contributing the biggest share in the production area with 2,047.75 hectares and the average yield per hectare with 13.46 hectares. Ranked second was the City of Digos with 1,476.38 hectares of production area and 12 hectares of average yield per hectare. Notably, the majority of the mango produce in Digos City came from Barangay San Roque due to the large mango farms situated in the barangay [4]. However, in the last decade, data from the Office of the Provincial Agriculturist (OPAG) – Davao del Sur in 2021 showed that the City of Digos ranked only second with a 21.46% share in mango production in the province. They were overtaken by the Municipality of Malalag as the leading producer of mango in the province with a 34.60% share in the produce.

Considering these actualities, the Davao del Sur State College approved an internally-funded project entitled, "Mango Tayo! Uplifting Davao del Sur Mango Industry through Digital Technology Phase 1" which has a program duration of 1 year starting in August 2023 and ends in July 2024 which addresses the problems stated above (poor induction and flowering intensity) and supports the movement for the good of the agriculture industry and alleviates food scarcity. Moreover, the project is separated into two sections: (1) MangoMo: Development of Mango Production Management AI-based Mobile Application and (2) Technology-based Extension Project for Davao del Sur Mango Growers and Contractors. Thus, using AI technology (MangoMo), the application assesses the maturity of mango flowering phenology from flower induction to fruitlet until the harvesting period. Also, real-time capturing of the mango site's soil nutrient parameters (NPK) was established. The application also captures and displays the current mango farm locations spraying the mango trees. Generally, the project aims to develop the MangoMo: Mango Production Management AI-based Mobile Application and conduct the Technology-based Extension Project for Davao del Sur Mango Growers and Contractors. Specifically, the program aims the following: (1) establish farm demo linkage; (2) gather data from the mango demo sites including soil NPK parameters and mango flowering stages image datasets; (3) develop the Android application embedded with Convolutional Neural Network model; (4) develop a soil nutrient analyzer prototype; (5) conduct technology testing and evaluation; (6) conduct relevant meetings, literacy seminars, fora, and symposia on related existing AI-based technologies in Mango Production Management and other emerging technologies in mango farming; and (7) capacitate and train the men and women partners on manipulating the MangoMo.

METHODS AND METHODOLOGY

Research Locale

Digos City is a coastal component city in the province of Davao del Sur, thus serving as the province's capital. The city has a land area of 287.10 square kilometers or 110.85 square miles, constituting 13.27% of Davao del Sur's total area. San Roque is a barangay located in the province of Davao del Sur's City of Digos. 1,659 people were living there as of the 2020 Census. This was equivalent to 0.88% of Digos' total population [5]. The Barangay San Roque is situated at approximately 6.7798, 125.2874, on the island of Mindanao as shown in Figure 1. Elevation at these coordinates is estimated at 114.5 meters or 375.7 feet above mean sea level.

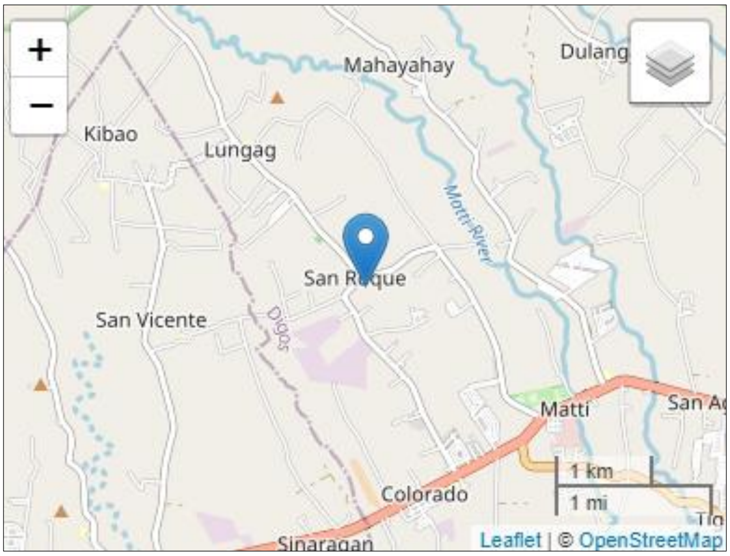

Figure 1. Barangay San Roque, Digos City map

Research Design

Figure 2 shows the Rapid Application Development (RAD) which was used in the research design of the study. It consists of four (4) phases, each with specific tasks and objectives, and all of the phases describe the software's life cycle up to delivery. The next development step starts when a stage is complete, and the results of the previous stage are conducted over into the new stage.

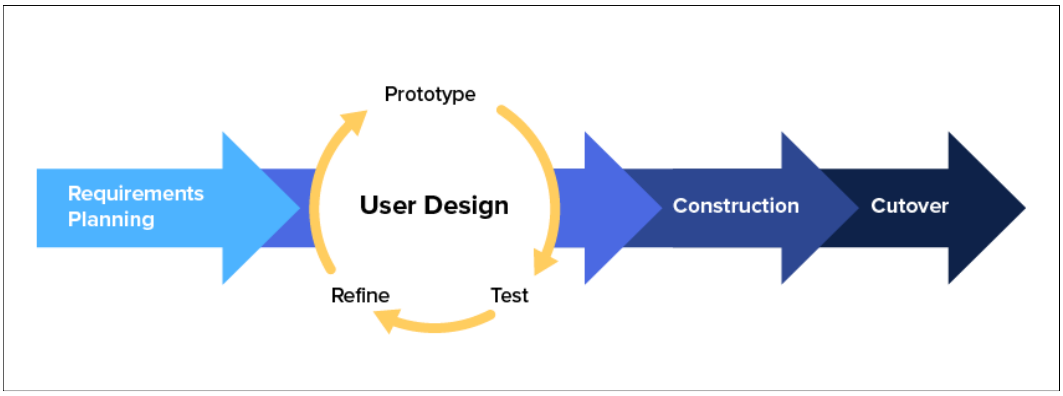

Figure 2. The rapid application development model

Requirements Planning

Preliminary activities that are under the requirement planning phase were conducted before the actual project implementation. To wit.

A. Coordination Meeting

The coordination meeting aimed to effectively disseminate the project's objectives and deliverables among key stakeholders, including the Office of the City Agriculturist Digos City, Mango Growers, and Contractors of the Brgy. San Roque United Farmers' Association. The event was hosted at Arnaldos Hotel in Digos City and saw active participation from diverse attendees.

The project team, composed of selected faculty members from the Institute of Computing, Engineering, and Technology, worked alongside representatives from the Office of the City Agriculturist. Additionally, 14 members of the SRUFA were present. This event also allowed the faculty members of the institution to disseminate new farming practices with the aid of Artificial Intelligence which is in line with the project's goal as shown in Figure 3.

The primary objective of the meeting was to gather valuable input and suggestions, particularly concerning the project's implementation phase. Discussions focused on identifying potential challenges, such as those related to mango farm management practices, and developing strategies to address them. This collaborative approach aimed to ensure a smooth execution of the project and to enhance its overall effectiveness and impact.

Figure 3. Coordination meeting with the partner-members

Also, the Mango Tayo team together with the DSSC Planning Officer and Extension Director participated in the Brgy. San Roque monthly session for the inclusion of the partnership and project in the Brgy. San Roque Development Plan, presented in Figure 4. This activity aims to have a strong collaboration with the barangay council and solicit their support for this program.

Figure 4. Barangay San Roque session with the Mango Tayo team participation

B. Selection of Demo Sites

The MangoMo program's effective development depends on choosing an appropriate demo site. This site should reflect the target user group, offer sufficient data, and make testing and application improvement easier. The main things to consider in choosing a demo site for MangoMo application development will be covered in this section.

Factors considered

Farmer collaboration. The mango farms owned by SRUFA members were the chosen demo locations. The willingness of the farmer members to select their farms as demo sites was greatly considered by the researchers.

Geographical location. The researchers selected the farms that are inside the geographical boundaries of Barangay San Roque, Digos City, Davao del Sur.

Data availability. Soil samples and mango flowering stages image datasets are the primary data considered in this study; therefore, the researchers mainly selected the sites in which the collection of these data is feasible.

Figure 5 shows the identified and agreed demo sites for the MangoMo Application development project. Demo sites 1 and 2 have the following location coordinates: latitude 6.7760526, longitude 125.2876223 and latitude 6.7754577, longitude 125.2902622. The demo site 3 has the location coordinates of latitude 6.7752371 and longitude 125.2926920.

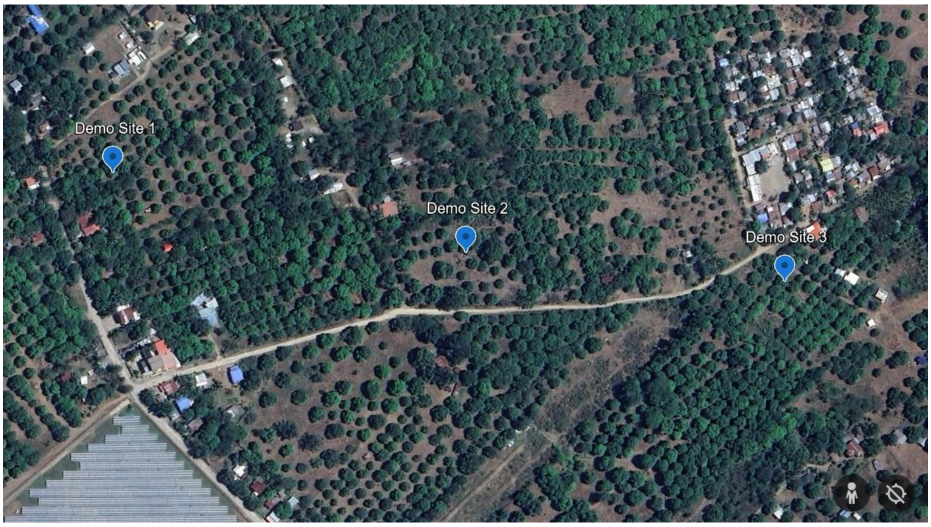

Figure 5. The identified demo sites in Barangay San Roque, Digos City

C. Data Gathering

The researchers conducted two data-gathering activities on September 27, 2023 and January 15, 2024 at Mango Farms in Brgy. San Roque, Digos City. Five (5) mango growers and contractors under San Roque United Farmers Association assisted and coordinated with the Mango Tayo Research members as shown in Figure 6. This activity gathered data/information in a measured and systematic manner to ensure accuracy and facilitate data analysis on mango farming. Three (3) demo sites have been identified; thus, mango tree and soil parameters have been gathered that will be utilized to calibrate and configure the MangoMo application.

Subsequently, a data gathering on the baseline data of the SRUFA mango growers has been conducted as shown in Figure 7, targeted to gather the partner-members' demographic profile, background information, and farming data.

Figure 6. Data gathering activities with the SRUFA partner-members

Figure 7. Data gathering on baseline data with the SRUFA partner-members

Image Dataset

The project team used 7000 actual images of Mango grouped according to 7 classes. Figure 8 shows the sample images of the 7 class, these images were manually labeled as datasets to train the MobileV2 Architecture of Convolutional Neural Network algorithm. The size of the images was set to 250x250 pixels in jpeg format. The datasets followed the 60:40 splitting methodology, where 60% consisting of 4,200 images, were used to train the architecture. While the remaining 40% or 2,800 of the images were used as a test image [6]. Table 1 shows the proper distribution of the datasets; it shows the four attributes used to train the model, additionally, the images used were validated by an Agronomy in the college who served as one of the technical experts of this project.

Table 1. Dataset distribution

Class	Training Data	Test Data	Total Images
Premature Leaf	600	400	1,000
Budbreak	600	400	1,000
Bud Elongation 1	600	400	1,000
Bud Emergence	600	400	1,000
Bud Elongation 2	600	400	1,000
Pre-Anthesis	600	400	1,000
Full Bloom	600	400	1,000

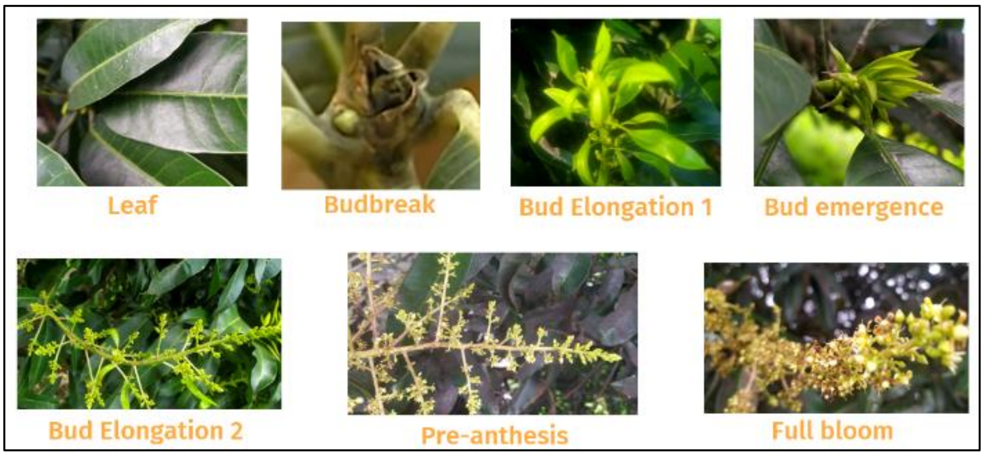

Figure 8. Image dataset on mango flowering stages

Data Preprocessing

After the dataset collection, the images were grouped and labeled according to their diseases or classes and resized into uniform dimensions of 224x224 px, then, were fed into the model for training. The manual hyperparameter tuning approach was used to perform hyperparameter optimization; in this method, the hyperparameter values were manually established by combining hyperparameters. The hyperparameters used in this research are the learning rate [7], batch size [8], and epoch with the following values of 0.001, 16, and 50 as most fitted.

User Design and Construction

Mango AI-based Application

MangoMo is poised to improve and reshape mango farming practices by developing an AI-powered application. By harnessing the power of artificial intelligence, we aim to create a comprehensive digital tool that empowers farmers to optimize their mango production, enhance fruit quality, and maximize their yield. Further, there must be a significant and swift shift to re-engineer agricultural activities at enormous scale and speed. The agriculture sector is searching for methods to use new technologies to boost yields due to population growth and climate change[9].

MobileNetV2, a lightweight DNN architecture designed for low-processing-capacity CPUs and mobile platforms, was utilized as the back engine of mango flowering stage classification. MobileNetV2 is regarded as the finest DNN since it performs exceptionally well in terms of accuracy and model size and, thus, is considered ideal for IoT applications [10]. Figure 9 shows the MobileNetV2 model architecture. It is made up of pooling, bottleneck, and 2D convolutional layers. In turn, the bottleneck layer is made up of 3 × 3 depth-wise convolution sub-layers, expansion, normalization, activation, and addition sub-layers. The expansion operation aims to increase the number of input data channels by a factor determined by the model's hyperparameters, hence expanding the data space. Each bottleneck layer is made up of 3×3 depth-wise convolution sub-layers, expansion, normalization, activation, and addition sub-layers. The normalization, pooling, convolution, and activation layers employ the corresponding operations that are necessary for the training and inference process. After the preprocessing of the dataset and setting of the hyperparameters, the dataset is then fed to the MobileNetV2 layers to automatically learn the spatial hierarchies of features, such as edges, textures, and shapes, which are important for recognizing objects in images as shown in Figure 9.

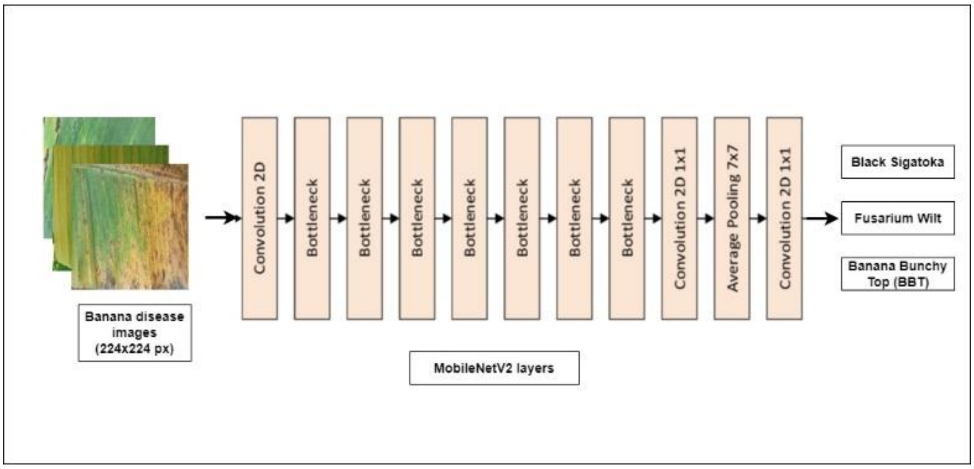

Figure 9. MobileNetV2 model architecture

Soil Nutrient Analyzer

Figure 10 shows the block diagram of the Soil Nutrient Analyzer developed alongside the application. This prototype was equipped with a microcontroller, sensors, and wifi module to capture the real-time NPK values of the soil and send them to the online database, then passed on to the mobile application. After soil laboratory analysis, the sensor was calibrated using the gathered soil samples from the demo site. Knowing the real-time values of the NPK in the mango farms is significant due to the effects of the values on the mango flowering and harvest. Thus, these data are essential before the proper application of fertilizers. Direct effects include helping farmers increase the quality of their mangoes and increase their earnings each harvest cycle [11].

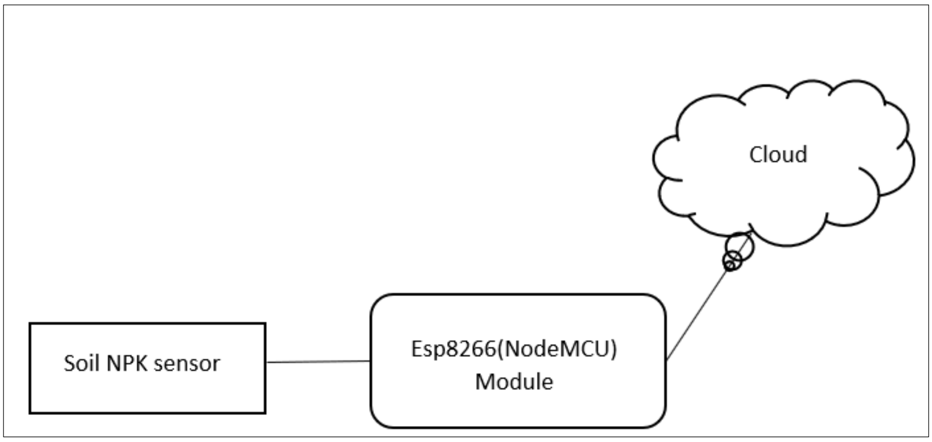

Figure 10. Block diagram of the soil nutrient analyzer

RESULTS

The SRUFA Members Profile

Figure 11 presents the demographic profile of the SRUFA partner-members showing the distribution of counts across gender, age ranges, and number of hectares owned. Among 18 members, 5 were male and 13 were female. The age range "51-60 years old" has the highest count, thus, conforms to India's statistics of mango farmers' age bracket [12]. While the age ranges "20-30 years old" and "71-80 years old" both have the lowest count. Further, in farm ownership, most of the farms owned by the members fall within the 1 - 2-hectare range with 55.56%. This suggests that a significant portion of the mango farms in this dataset are medium-sized operations. Farms smaller than 1 hectare account for 27.78% of the total, while larger farms (between 2.1 and 4 hectares) comprise a smaller share of 16.67%.

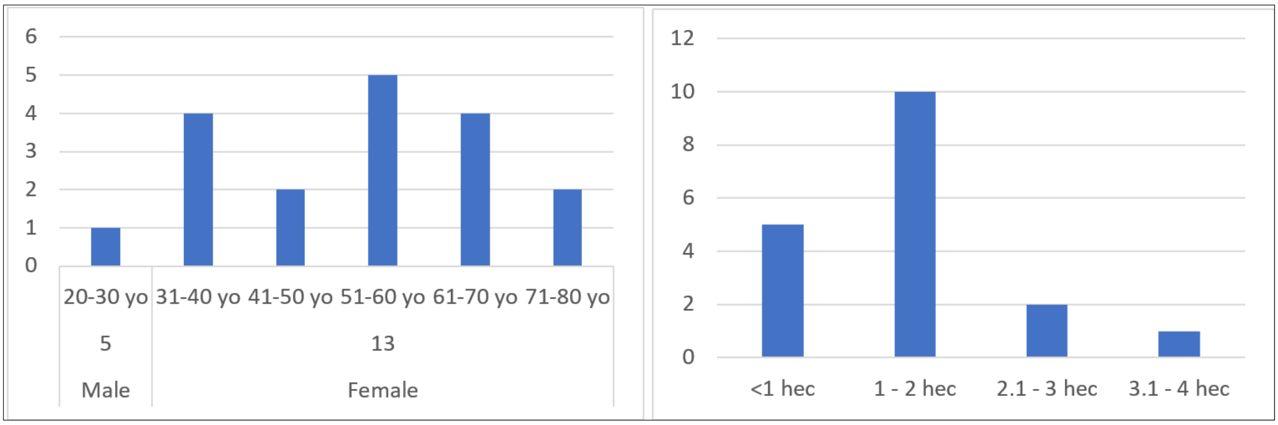

Figure 11. Demographic profile of the mango farmers

MangoMo AI-based Application

Figure 12 shows the modules in the MangoMo Application elaborately: soil NPK readings from the Soil Nutrient Analyzer device; real-time visualization map of the ongoing spraying activities; AI-based mango flowering stage classifier; and the spraying recommendation notification. The recommendation feature is the product of the setting of the schedule based on DAFI (days after flowering induction) [13]. What it does is recommend or signal the next possible schedule every single day from day 1 to the last day. The last day signal implies the end of the particular age and the beginning of the next stage. If there are no rapid changes in the mango flowering then the last day is the perfect day for recapturing and sending notifications to the sprayer and resetting the next possible schedule of the next stage.

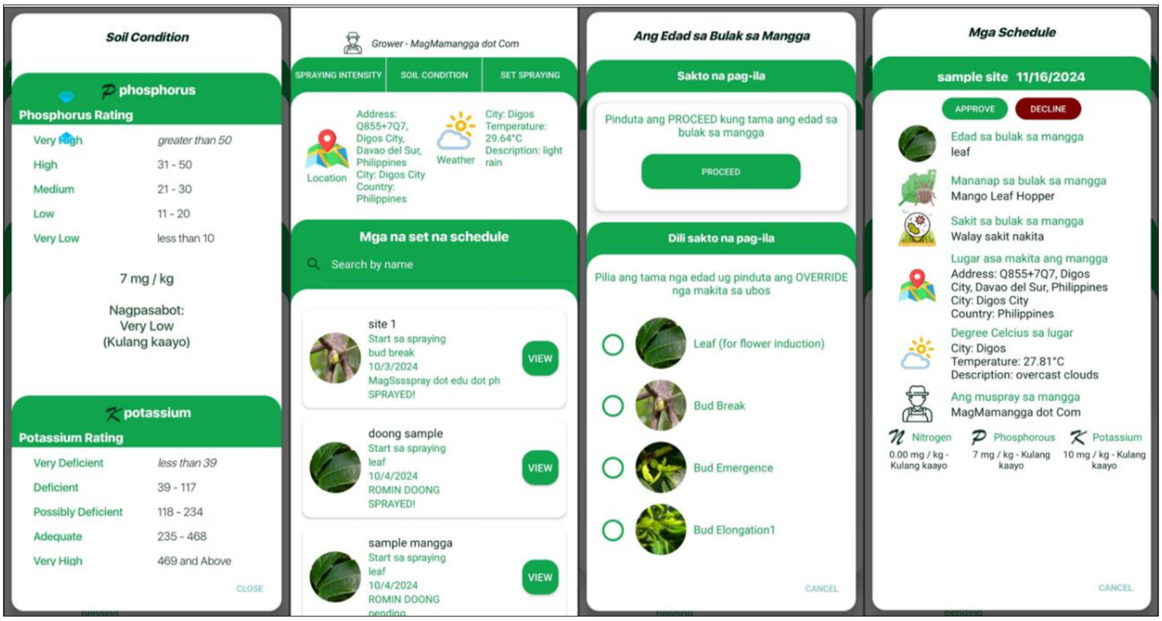

Figure 12. The MangoMo application modules

Soil Nutrient Analyzer

The developed Soil Nutrient Analyzer shown in Figure 12 is a portable device deployed in the demo site purposely to capture the real-time NPK values of the soil. Equipped with IoT sensors and wireless transmission of data capability, the device can send real-time values to the end of mango farmers aiding them in their decision-making on what fertilizer to apply. Further, the NPK sensor is equipped with high measurement accuracy, fast response speed, and good interchangeability. Thus, it is completely sealed, resistant to acid and alkali corrosion, and can be buried in the soil for long-term dynamic testing.

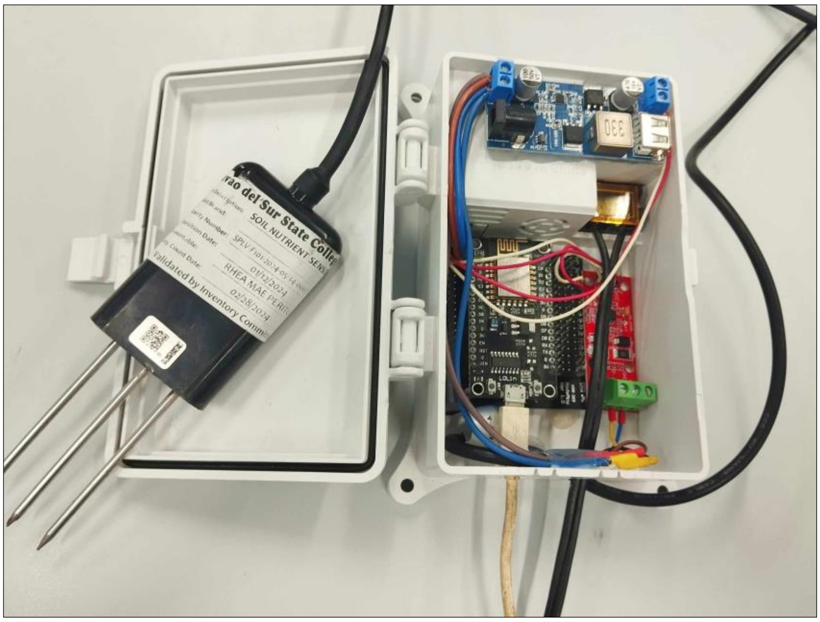

Figure 12. The developed soil nutrient analyzer

Technology Evaluation and Testing

Using the ISO 9126 Software Quality Model metrics: Functionality, Reliability, and Usability, the developed technology was tested and evaluated by the 18 SRUFA partner members. The data in Table 2 indicates a generally positive reception to the MangoMo application's functionality, with a majority of users rating it as **Strongly Agree** (53%) or **Agree** (40%). This suggests that the core features of the app are meeting user expectations and providing value. However, the 7% rating of the app as **Fairly Agree** indicates areas for improvement. In reliability, a majority (60%) rated it as Strongly Agree. This suggests that the application performs well in most cases and meets user expectations. Moreover, in usability, the result indicates a high level of user satisfaction with the MangoMo mobile application. With a combined 100% of users rating the app as either "Strongly Agree" or "Agree," it suggests that the app is largely meeting user expectations and needs.

Furthermore, based on the result of the evaluation of the Soil Nutrient Analyzer as shown in Table 3, the result indicates a high level of satisfaction with its functionality, with 81% of respondents rating it as "Strongly Agree" and 19% as "Agree." This suggests that the analyzer generally performs well in meeting user expectations and needs.

Overall, the MangoMo application and the Soil Nutrient Analyzer were in the majority rated as “Strongly Agree”, indicating that both meet the user expectations, perform well, and meet a high level of satisfaction from the users.

Table 2. Evaluation results of the MangoMo application

Metrics	Strongly Agree	Agree	Fairly Agree	Disagree	Strongly Disagree
Functionality	53%	40%	7%	-	-
Reliability	60%	29%	11%	-	-
Usability	69%	31%	-	-	-

Table 3. Evaluation results of the soil nutrient analyzer

Metrics	Strongly Agree	Agree	Fairly Agree	Disagree	Strongly Disagree
Functionality	81%	19%	-	-	-

User Training Evaluation

The Mango Tayo team conducted a series of user training sessions with the SRUFA partner members on the manipulation of the developed technology. Figure 13 presents the result of the training 1 evaluation with 25 participants. The result depicts the rating results: 51% of participants rated “Strongly Agree”; 42% rated “Agree”; and 5% rated “Fairly Agree”. Whereas, none of the participants rated Disagree and Strongly Disagree. These findings indicate that the MangoMo Application User Training 1 has a good overall evaluation due to its successful delivery to the mango farmers.

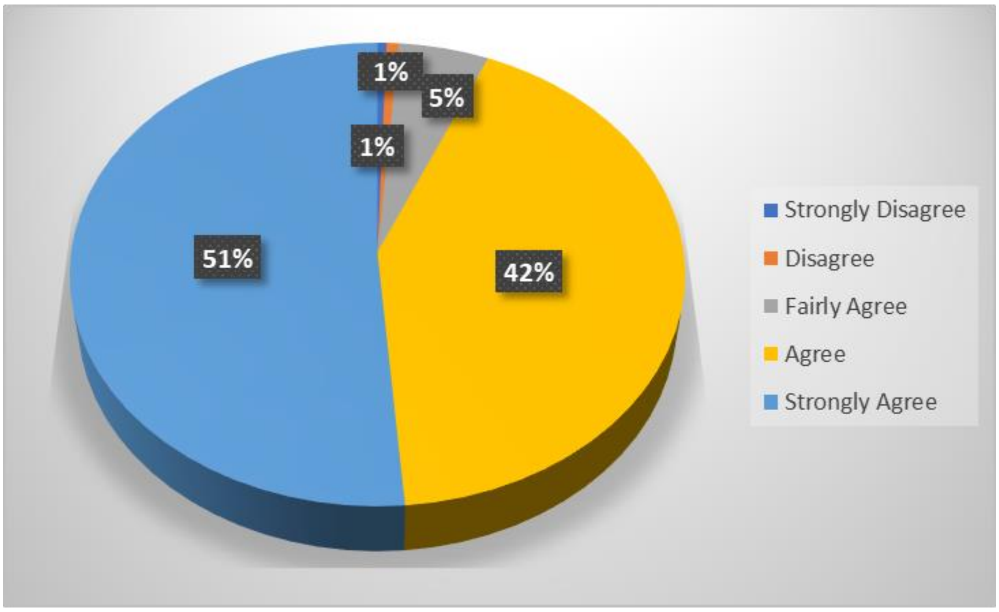

Figure 13. The user training 1 evaluation result

Moreover, Figure 14 presents the result of the training 2 evaluation with 26 participants. The result depicts the rating results: 83% of participants rated "Strongly Agree"; 16% rated "Agree"; and 1% rated "Fairly Agree". Whereas, none of the participants rated Disagree and Strongly Disagree. These findings indicate that the MangoMo Application User Training 2 has an excellent overall evaluation due to its successful delivery and equipping farmers with new knowledge on innovative farming.

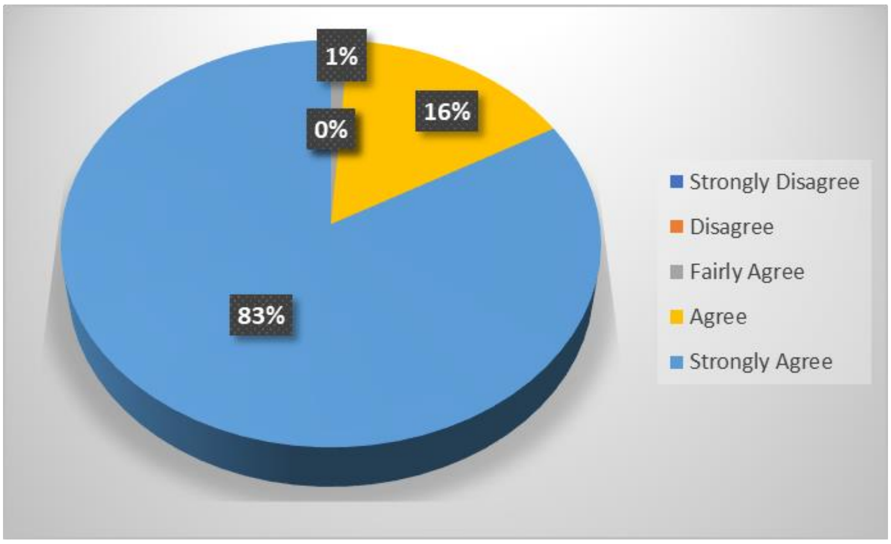

Figure 14. The user training 2 evaluation result

CONCLUSION

With the development of new methods of improving crop yield and handling specifically in mango farming, one can readily see currently: technology-driven, innovative, and partnerships between farmers. The Mango Tayo Program considered all these aspects and highlighted the role of various technologies, especially AI and IoT, to make agriculture smarter and more efficient to meet future expectations. Thus, the program developed an AI-based Smart application for mango production management, utilizing cutting-edge technologies in smart agriculture. Further, the application meets the user expectations, performs well, and meets a high level of satisfaction from the users. Further, the conducted community engagement and activities to capacitate the women and men mango growers and contractors in Digos City with the use of the developed technology were found to be successful in delivery and equipping farmers with new knowledge on innovative farming.

However, despite the success of the conducted series of training, challenges were still faced by the team given that most of the farmers are 37 years and older. There is a need for more technical and technological literacy to be conducted so that the farmers will be more accustomed to navigating the developed technology. Further, in Phase 2, it is recommended to conduct activities that will measure the socio-economic impact of the program on the community partner members. Moreover, recommendations on integrating solar technology to power the Soil Nutrient Analyzer will also be taken into consideration since most of the mango farms are located in areas with no electricity. Also, since weather is a vital component in growing mangoes, developing micro weather stations in the demo sites is considered. Nonetheless, the program was found to be successful in achieving its objectives—enabling the community partners to use cutting-edge technology in farming.

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DATA AVAILABILITY

Data sharing is not applicable to this article.

CONFLICT OF INTEREST

None

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