30 Mar 2018

Treenut Saithong, PhD
Saowalak Kalapaulak, PhD
Jittrawan Thaiprasit, PhD
Udom Sae-Ueng, PhD
Kitsanai Charoenjit, PhD

Concept proposal

Project title: Precision agriculture to increase productivity and improve water use efficiency **–** using cassava as a case study crop**.**

Overview and rationale

We are nowadays pressured by global problematic issues of food shortage and climate change crisis. These problems are cause-effect related and highly associated via many factors. The rapid increase of food demand in contrast to the limited available resources leads to the initiation of circular economy model that aims to balance the existing resources, waste spoilage, and demands. A circular economy is a rationale to escape from the "take-make-waste" system of the current industrial economy by minimizing resource inputs, waste emission and energy leakage. It is the global systematic regime, in which all processes from production to consumption are completely related and compensated through recirculation of by-products of an individual process to others. In Figure 1, agricultural production is located at the upstream of overall processes where the natural resources are enormously consumed. It is thus the first place to target in problem solving, followed by the concerns of other sectors till fulfill the balance of the whole systems.

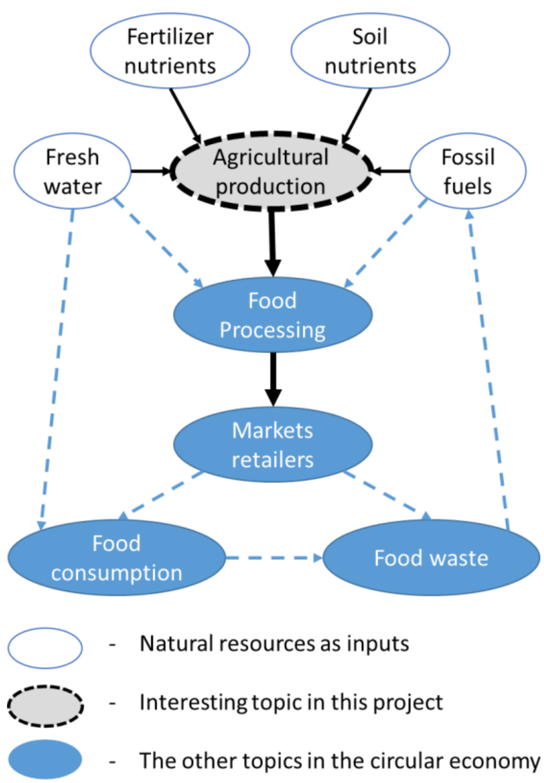


Figure 1 *The model of circular economy showing the relation of demands from different sectors and natural resources, and locating where take-make-waste on the model*.

To alleviate the over-consumption in agricultural production according to circular economy, environmental concerns are needed to take into account in rationale to improve crop yield as well as productivity to secure food production for people on earth. Improvement of crop productivity (per cultivated area) while reduction of over-demanded resource-used is a strategic research of all agricultural sectors, "produce more with less". Not only does it benefit farmers to sustain their careers by reducing productivity cost and obtaining more profit, but it also gives more valuable profit to everyone in the world for food security and environmental-friendly society. In order to gain high crop yield under less resources, *i.e.* water and fertilizer, the precision farming is one of the most employed rationales to reach the goal. Under the framework of precision farming, putting the right thing on the right time at the right place, it is feasible for applying it to several levels of private sectors from big private company to small farmers. For this big adaptation, farmers have to change from traditional farming with labor intensive to knowledge-based and digital technology-based farming.

Precision farming or precision agriculture is the key of new generation technologies in agricultural sector by integration of various technologies including big data gathering and analysis to provide decision support systems (DSS), and digital and automation technologies for controlling multi-levels machines. In Europe and the United State, precision agriculture has become the most influential trends in the agricultural sector as seen in a growing number of advanced-farmers. However, the application of precision farming in the world is very narrow range because of lacking sufficient data for developing the decision supporting system that is specific to each crop plant. Therefore, the huge amount of data involving crop plantation system, weather information, soil information and physiological data of plant under various stages of development are vital for the development of the decision support systems.

Among staple crops, cassava is one of the high impact crops for world population. Cassava is the third most important source of food carbohydrate in the tropics, after rice and maize (Montanage et al., 2009). Approximately 500 million people in the world depend on its root as a major carbohydrate (or energy) source, because it gives more energy per area than other major crops (Montanage et al., 2009). Cassava products are primarily used for human consumption through trades of fresh roots and processed products in markets. This crop is vital in many roles on human purposes. Firstly, it is needed for food security in many developing countries. Secondly, it is required for feeding in industrial uses and exporting by traders in the world. Lastly, it provides a livelihood for millions of small-scale farmers.

For the role in food security, until now, cassava holds the position as a primary food security crop in Africa and many developing countries due to its resistance to drought and disease, growing in poor soil, being cheap and reliable food source. Approximately 80% of the world population lacks a basic food intake, especially in Africa, where there is a number of hidden hunger and food insecurity (Abass et al., 2018); therefore, cassava can become a nutritional resource for malnourished population in the world. In Figure 2, million people in Africa, Asia and Latin have consumed cassava as a staple food in daily life (largest circle of Figure 2). In comparison with cereal and wheat flour, cassava flour gives very high in dietary fiber (4.92–5.6% insoluble fiber and 3.40–3.78% soluble fiber) and starch content (64%-72%). Moreover, cassava root has very low protein content, especially in the sulfur-containing amino acid (methionine and cysteine) that is an advantage for bread making. In addition to the roots, the leaves of the cassava plant are edible

and rich in protein (Abass et al., 2018). With this regarding, it is a promising crop plant for sustainable food and feeds for the world population under the climate change crisis.

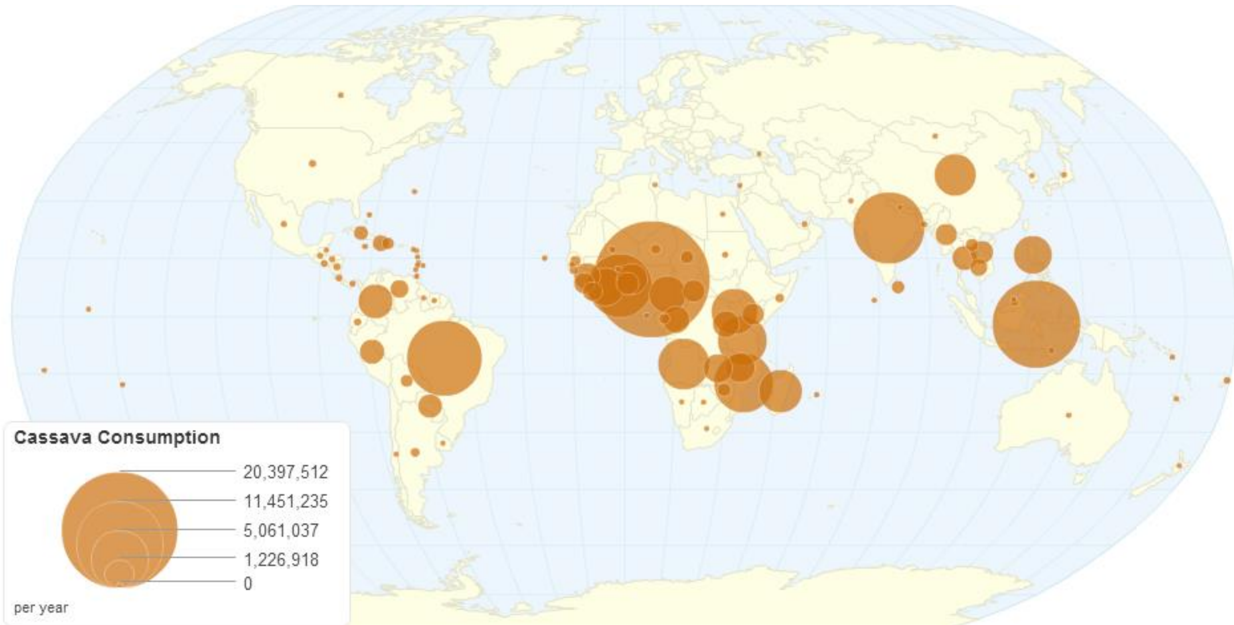


Figure 2 *Cassava consumption by country*. (*Source*. *Cassava Consumption by Country, ChartsBin.com, viewed 15th March, 2018, http://chartsbin.com/view/34825*).

For the role in industry sector, about 60% of world production is located in five countries Nigeria, Brazil, Thailand, Indonesia, and the Congo Democratic Republic (Prakash, 2005), which collectively play a role as a leading group of cassava traders. The majority of world trade in cassava is in the form of pellets and chips for feed in domestic industries or export to trading partners (Figure 3). Additionally, the balance of cassava primary product is mostly in starch (or flour) for food processing and industrial use, and subsequently, in the form of ethanol for fuel production and using as a solute in many purposes (Figure 3). Whereas in the form of fresh root is very little traded because of its limitations from bulkiness and perishable character of storage root.

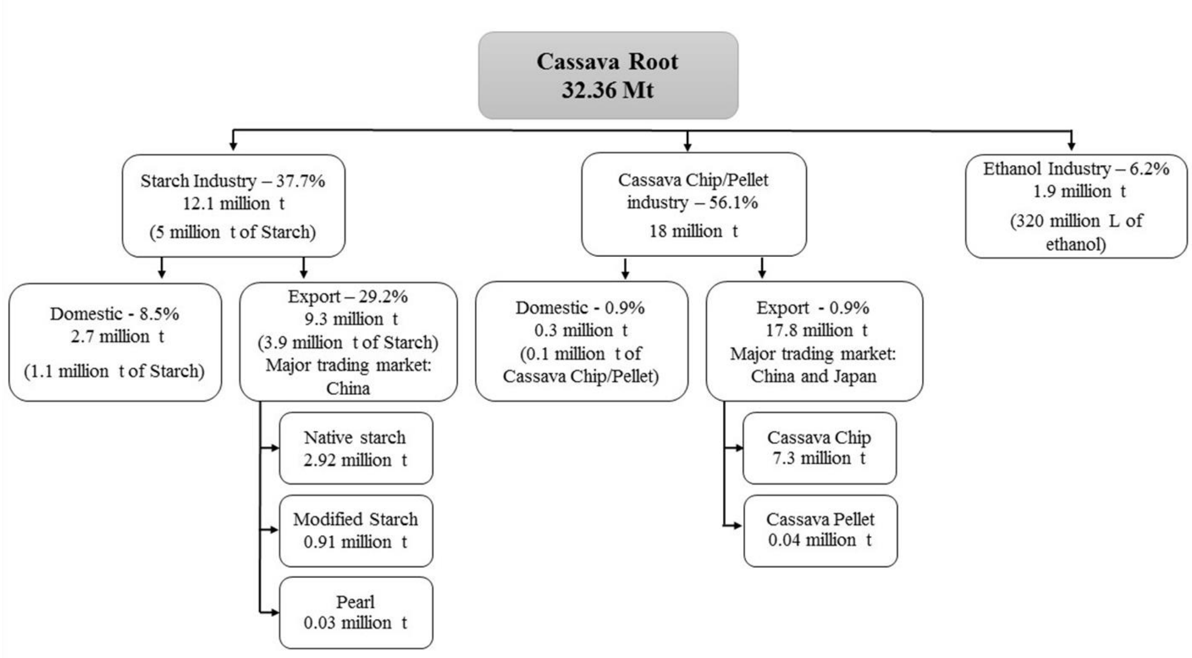


Figure 3*A simplified diagram of cassava starch industry starting from harvested cassava root to processed products with its quantities* (*from Walintorn's slide*).

During the process of cassava industry, a significant amount of waste is generated that include solid and liquid wastes such as washing of the cassava roots, peeling of cassava tubers, pulping or grating, fermentation and dewatering of cassava pulp, sieving, roasting, drying and packaging (Figure 4). Water released from washing process can have a potentially harmful effect on the environment, if it is produced in large quantities because of acidic with high organic matter and high cyanide content (Sackey and Bani, 2007). A number of studies have been conducted to reduce toxic waste and improve yields. Key challenges of these studies are to solve the perception of 'waste as a problem' to 'waste as a resource' in terms of environmental awareness. The existing solutions include land filling, animal feed, fermentation of solid residue, use of waste water for irrigation, infiltration of waste water into the soil, storage in aerobic or anaerobic lagoon and use of anaerobic digesters (Sackey and Bani, 2007). Currently, many efforts change these waste lagoons in cassava industries to produce valuable energy including in Thailand (Veiga et al., 2016; Sáncheza et al., 2017).Since the cassava waste will be increased as the rising cassava productivity (Figure 4), the wealth of treated waste would be growing up respectively. These processes are additional value to the cassava industry as following the model of the circular economy with the environmental awareness.

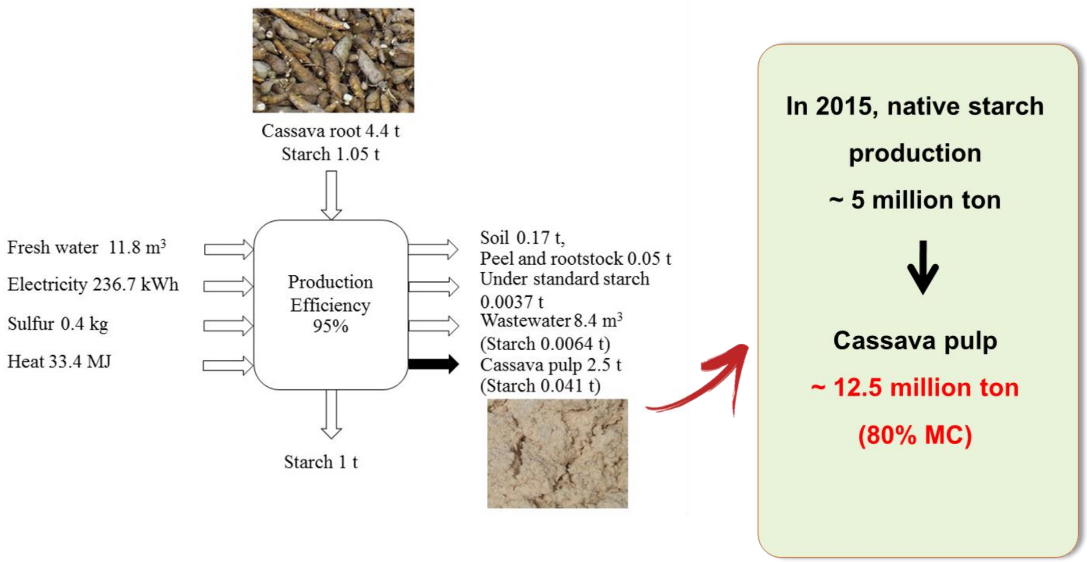


Figure4*A simplified input-output diagram of the cassava starch production process*(*from Walintorn*'*s slide*).

In Thailand, cassava is one of the top-important economic crops including rice, sugarcane and rubber tree. Thailand is the second largest producer of cassava in the world (after Nigeria) and is the largest exporter, accounting for a 50–75% global market share for cassava starch (FAOSTAT, 2016).A majority of cassava products in Thailand exports to Europe and China as dried chips for animal feed. In the case of cultivation, most of Thai farmers propagate cassava through its stem cutting that is easy-to-planting, saving production cost, and less time-consuming. Although cassava is an easy propagated and well-adapted plant, most of Thai cassava growers have low income because they give improper inputs including water and fertilizer to the field. Over the past years, most of the gains in overall production are attributed from an increase in the area of land cultivated rather than an increase in yield (Figure 5). One of the major challenges for cassava producers is driving the conventional cultivation to a modern cultivation using precision agriculture to reaching the maximum yield of each cassava cultivar. Two of the major constraints to development of cassava production are cultivation on unsuitable area, and poor cultivation management. To increase farmer income, precision farming would be a promising tool to handle this problem by reducing cassava production costs and increasing root yields.

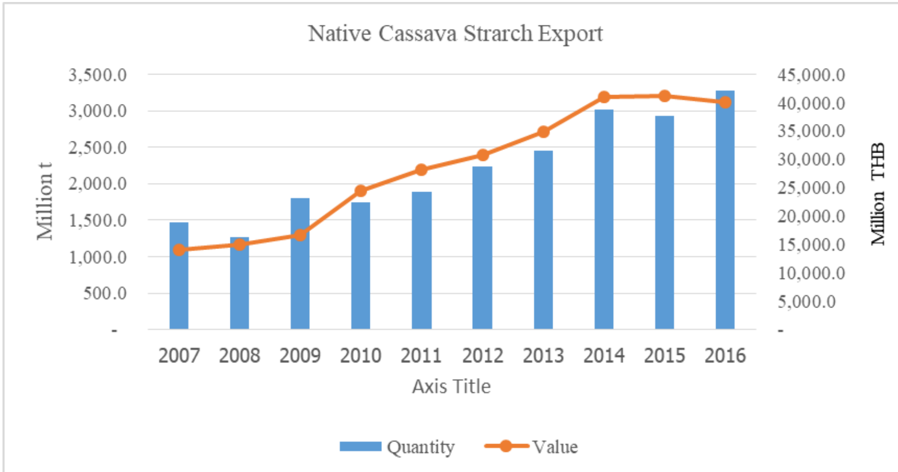


Figure 5 *Trend of native cassava starch export in Thailand* (*FAOSTAT, 2016*).

Sequential development of precision farming for cassava production should start at a decision supporting system that is a bottle-neck and a critical point of running-through the whole-system (Figure 6). With this regard, sufficient and accurate data are the primary key of the system development. For a decade, Thai researchers have generated data regarding irrigation and fertigation to increase yield of cassava, but these existing data are not wellutilized in precision agriculture aspect because of their incompatible format. Thus, to utilize the existing data, data management and analysis is the first priority.

In order to develop the decision support systems of cassava for water-and fertilizer used efficiency, two phases of the development have been proposed. For the first phase, the existing data of cassava plantation including cassava cultivar and its physiological data under various developmental stages, weather and soil information, and irrigation system will be reviewed and collected as the input for DSS construction in order to push up the utilization of invaluable accumulated data involving cassava plantation.For the second phase, remote data and massive information from close-range remote sensing using aerial drone, multi-spectral and thermal cameras will be proposed as the technology platforms for increasing input data as the important key for improving the accuracy of DSS in cassava. Moreover, the validation of developed DSS will be validated in the real cassava fields in the final step for completing the goal for increasing yield with efficient irrigation and fertilizer inputs. The proposal can be organized into three work plans according to Figure 6. The pilot experiments are designed to ensure an initiation of precision farming framework for cassava crop production in Thailand by using existing research data. The valuable data will be managed and tested in real-time systems. To sustainably implement this research by farmers, the new technology is firstly demonstrated in experimental plots and then extended to real cassava farms of our network farmers and finally expanded to other groups of farmers.The outputs of this project is expected to the yield and productivity of cassava with respect to the current practice of conventional cultivation method. The project would be a pilot study that could inspire cassava farmers and other crop farmers to use precision farming concept to elevate crop productivity without making trouble to our natural resources.

Goal

To demonstrate the potential of precision farming to increase cassava yield improvement under water-use and fertilizer-use efficiency

Strategy

Building both technology and human capability on precision agriculture to turn futile resource use and unpredictable crop production into precise as well as optimized resource use and sustainable farming

Objectives

To build the capability of Thailand cassava farmers on precision agriculture that optimizes cassava production, and maximizes production with minimized water and fertilizer use. To achieve the overall objective, a decision support system (DSS), which is an essential part of precision agriculture framework (WP1), will be developed as well as the required supporting technology of measurement (WP2). Once the framework and technology are launched, all knowledge and technology platform will be transferred to cassava farmers through demonstration, workshops and social network activities (WP3). The specific objectives for individual work plan (WP) are listed below.

WP1: Development of decision support system (DSS) from existing data

1. To gather the currently available data of cassava cultivation
2. To construct the data management system that supports the integration of individual-based knowledge to be integral-based information for cassava precision farming
3. To develop a decision support system (DSS) for cassava production by aiming to improving yield and resource (*i.e.* water and nitrogen fertilizer) use efficiency from the currently existing data
4. To identify knowledge gap as well as data required to improve the effectiveness and accuracy of the decision support system (DSS) for cassava production, which will be an input for WP2

WP2: Development of decision support system (DSS) from real time and prediction data

1. To develop real time data acquisition of cassava cultivation using close- range remote sensing technologies

(aerial drone imaging and weather station)

2. To develop geo-information mining data on cassava cultivation
3. To develop artificial intelligent (AI) modeling for automated prediction of cassava cultivation

WP3: Capacity building of precision farming for Thai cassava farmers

1. To implement the precision farming with the DSS platform utilization on the real cassava fields in Thailand
2. To increase the number of precision cassava farmers as the leading farmers for their local communities
3. To improve the accuracy, the performance, and the utilization of the DSS platform via the feedbacks from the real cassava farmers

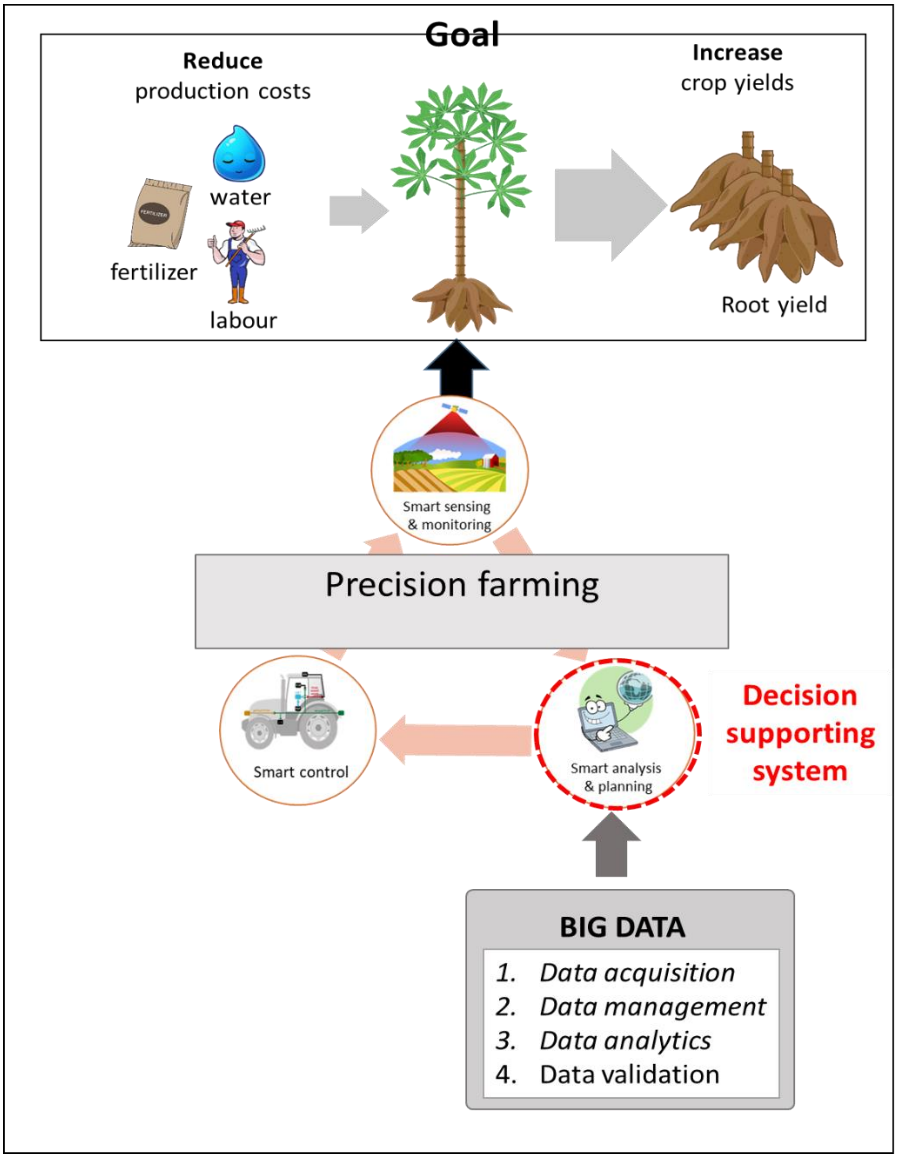


Figure 6 *Conceptual framework of precision farming and decision support system*

Goal To demonstrate the precision farming potential to increase cassava yield improvement under water-used and fertilizer-use efficiency

Strategy Building capability on precision agriculture, in terms of technology and human, to turn futile resource-used and unpredictable crop production into precise as well as optimized resource-used and sustainable farming

Objective To build the capability of Thailand cassava farmers on precision agriculture that optimized cassava production, maximized production with minimized water and fertilizer used.

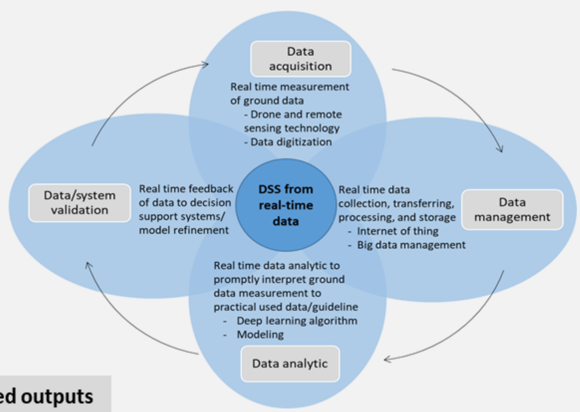
WP1 Develop decision support system (DSS) from existing data

- Data acquisition:
  - Data survey, review
  - Data assembling and collection
- Data management: develop central platform for data resources.
- Data analytic: utilize the existing data for improving cassava yield with efficient water used through modeling
- Data/system validation: Field validation of decision support system (DSS)

Expected outputs

- 1st establishment of decision support system (DSS) for cassava production from the current available data
- Identification of data required to fulfil precision farming for cassava production
- Identification of gap technology towards precision farming for cassava production

WP2 Develop decision support system (DSS) from real time data



Expected outputs

- More powerful decision support system (DSS) for cassava production from real-time measurement data
- Establishment of the required technical capability toward precision farming in cassava production

WP3 Build capability of farmers on precision farming

- Workshop and training
- Field demonstration

Expected outputs

- Increase numbers of precision farmers
- Towards the implementation of precision farming for cassava production in real farmer field.

Figure 7 *Conceptual framework of proposal*

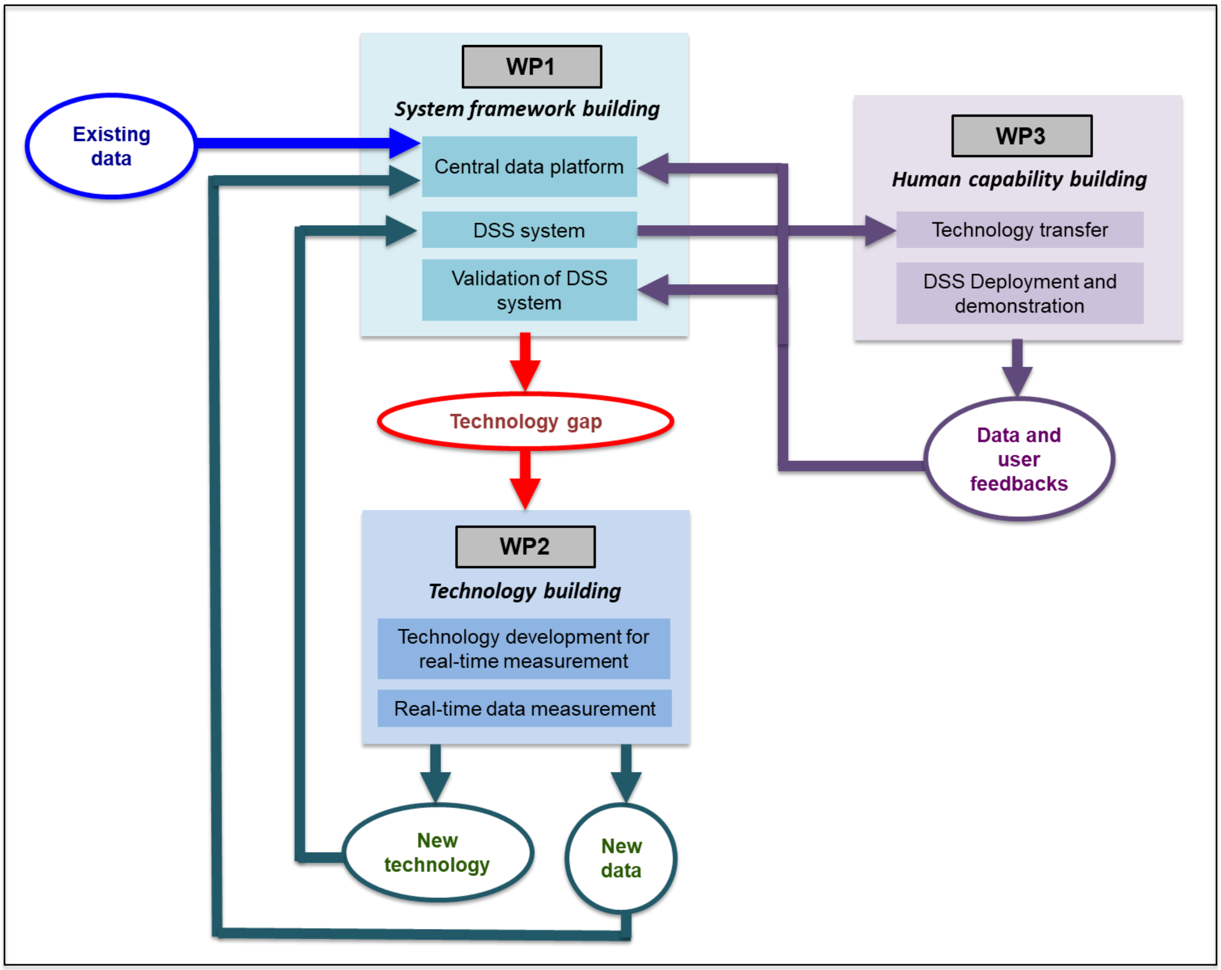


Figure 8 *Workflow of work plans* (*WP*) *in the proposal*

Implementation

WP1: The large amount of existing data from several research groups in Thailand requires efficient data management and analysis. The existing data of cassava farming include the data from weather stations, the data from the fields, and the data at the single-plant level. The data from weather stations consist of humidity, temperature, photosynthetically active radiation (PAR), rain precipitation, and wind direction and speed.The data from the fields consist of soil moisture and soil temperature at different soil depths. The data at the single-plant level mainly consist of cassava physiology data such as weight, height, leaf area, and root distribution.All data must be assembled and reviewed (data acquisition). The data require a uniform format for the same understanding and for further use during the project timeframe and in the future. The format will require geographic information, time (day of year), soil type, irrigation rate, fertigation (N, P, K) rate, and other related information. This step of data management will lead to the central platform for the project such as cloud system. After the completion of the data management

system, the data analysis can be initiated. For the first step, each environmental factor can be analyzed and be related to the cassava response in the field or production scale (tons per rai (1,600 sqm)). The relatively simple model of cassava biomass (above ground and storage root) or cassava yield can be built from statistical analysis as the initial model for further adjustment.The focuses of the model are water use efficiency (irrigation) and fertilizer use (fertigation). Lastly, the model will eventually become a critical part of the so-called first version of the decision support system.

Since the incompletion of the model is expected due to insufficiency of existing data, the related data that are needed for more reliable data will be identified. Also, such data can potentially require other different technology for data collection. The technological gap will be thusly identified as well.

WP2: With the established platform for data management and analysis, cutting-edge technologies, which are identified in WP1 for large-scale analysis using integration of sUAS (small Unmanned Aerial System or Drone) and Satellite Images and Weather micro station, can be employed in real-time data measuring. The very high-resolution remote sensing technology includes multi-spectral camera and thermal camera for producing vegetation indexes such as NDVI (Normalized Vegetation Index), VARI (Visible Atmospherically Resistant Index), ENDVI (Enhanced Normalized Different Vegetation Index), OSAVI (Optimized Soil Adjusted Vegetation Index), RDVI (Renormalized Different Vegetation Index) and VARI (Vegetation Adjusted Reflectance Index), Soil-moisture and 3D terrain information. Using the empirical mathematic model, AI machine learning for linking between the remote sensing data and ground data (WP1). The newly acquired data will be cooperated (or updated if necessary) into the existing data in the central platform.The tools of big data will play an important role in managing the huge amount of the new data. While the first version of the model is initiated, artificial intelligence and machine learning can be attractive tools for building a constantly adaptive model and for upgrading the model according to the new data. As a result, the DSS will be refined and extended, and the technological capability will be built in WP2, hence moving closer to the actual deployment of cassava precision farming.

WP3: The focus of WP3 is the technology transfer step to the target groups. The utilization of the established DSS will be demonstrated in the cassava demonstration fields and will be expanded to the target groups such as the cassava farmers, who are interested in the application of the cassava precision agriculture, via trainings and workshops.The follow-up, troubleshooting, and consultation regarding to the DSS during the cultivation period will be conducted through the communications on the social media activities. Both data and feedbacks from the target groups will be used as an input to further improve the DSS such as data from real cassava fields, functionalities, and interface.

Expected outputs

1. Central platform for data management of cassava
2. Decision support system (DSS) for cassava
3. New technology platforms for real-time data collection and data analysis
4. Leading groups of smart cassava farmers

Expected outcomes

1. A pilot system of precision farming for cassava production in Thailand
2. Increased cassava productivity with optimized resource (water and fertilizer) use
3. Increased income leading to sustainable economic for famers

4. Technology and human resource to pursue sustainable agriculture under climate change crisis
5. A pilot system of precision farming for other crop production in Thailand

Project time frame

3 years

Overall project time line

Work plan	Year 1		Year 2		Year 3	
	M1-M6	**M7-M12**	**M1-M6**	**M7-M12**	**M1-M6**	**M7-M12**
Work plan 1: Development of decision support system (DSS) from existing data						
1. Data acquisition	↔	↔				
2. Data management		↔	↔	↔	↔	↔
3. Data analytic		↔	↔	↔	↔	↔
4. (DSS) System validation					↔	↔
5. Overall analysis the developed DSS and identify the gap of knowledge (data) as well as required supporting technology						↔
6. Reporting and documentation		↔		↔		↔
Work plan 2:Technology development for decision support system (DSS) from real-time data						
1. Data acquisition: using close-range remote sensing technologies			↔	↔		
2. Data management: using agri-geospatial data			↔	↔	↔	↔
3. Data processing: using AI for linking between ground and close-range remote sensing data.			↔	↔	↔	↔
4. Overall analysis the technology developed DSS real time and prediction data: identify the key technology and minimize complex technology deployment to support technology transfer in WP3						↔
5. Reporting and documentation				↔		↔
Work plan 3: Capacity building of precision farming for Thai cassava farmers						
1.Technology transfer to the target groups			↔	↔	↔	↔
2.Collaboration and communication with the target groups			↔	↔	↔	↔
3.Obtaining data and feedback for the DSS improvement				↔	↔	↔
4. Reporting and documentation				↔		↔

Overall project estimated budget (27,485,000THB for 3 years)

Activities	Budget (THB / 3 years)
WP1	
1. Data acquisition (Data survey and review, Data assembling and collection, Data filtering and organization)	3,200,000
2. Data management (Data management system/database design, Data file format design, Data transformation, Central platform of data resource development)	3,200,000
3. Data Analytic (Model development, Decision support system development (DSS))	1,200,000
4. (DSS) System validation (Design optimized plantation practice based on DSS system, Field plantation and ground measurement, Assessment of DSS performance)	1,750,000
5. Overall analysis the developed DSS and identify the gap of knowledge (data) as well as required supporting technology	200,000
6. Reporting and documentation	30,000
Total	**9,580,000**
WP2	
1. Data acquisition: using close-range remote sensing technologies	9,660,000
2. Data management: using agri-geospatial data	3,300,000
3. Data processing: using AI for linking between ground and close-range remote sensing data.	525,000
4. Overall analysis the technology developed DSS real time and prediction data: identify the key technology and minimize complex technology deployment to support technology transfer in WP3	200,000
5. Reporting and documentation	200,000
Total	**13,885,000**
WP3	
1. Technology transfer to the target groups	3,000,000
2. Collaboration and communication with target groups	500,000
3. Obtaining data and feedback for DSS improvement	500,000
4. Reporting and documentation	20,000
Total	**4,020,000**
Total budget of project	**27,485,000**

WP1 Development of decision support system (DSS) from existing data

Objectives

1. To gather the currently available data of cassava cultivation.

2. To construct the data management system that supports the integration of individual-based knowledge to be integral-based information for cassava precision farming.

3. To develop decision support system (DSS) for cassava production, by aiming to improving yield and resources (*i.e.* water and nitrogen fertilizer) use efficiency, from the currently existing data.

4. To identify knowledge gap as well as data required for improving the effectiveness and accuracy of the decision support system (DSS) for cassava production, which will be an input for WP2

WP1 summary

Cassava is one of the top economic crops of Thailand. Accordingly, the research program towards yield improvement has been run in various aspects, including breeding, optimization of cultivation practice, pest and disease controls. Intensive studies that have been conducted for decades have earned the assets in terms of valuable basic knowledge and data of cassava to the country. However,the large amount of existing data from several research groups in Thailand requires efficient data management and analysis. The existing data of cassava farming include the data from weather stations, and the data from the fields, and the data at the single-plant level. All data will be assembled and reviewed (data acquisition). Then, the data will undergo generalization process, where the uniform standard format of data will be designed to provide the same understanding, and finally will lead to the central platform for data repository and utilization, probably via cloud system. The data management system will facilitate the establishment of data analysis. For the first step, each environmental factor will be analyzed and be related to the cassava response in the field or production scale (tons per rai (1,600 sqm)). The relatively simple model of cassava biomass (above ground and storage root) or cassava yield will be built from statistical analysis as the initial model for further adjustment. The focuses of the model are water use efficiency (irrigation) and nitrogen fertilizer use (fertigation). Lastly, the model will eventually become a critical part of the so-called first version of the decision support system. The established system will be validated with field data from experimental plot. The results of model assessment will allow us to identify the insufficiency of existing data and the required technology for supporting measurement. This information is essential input information in extend to develop better performance DSS for cassava production in WP2.

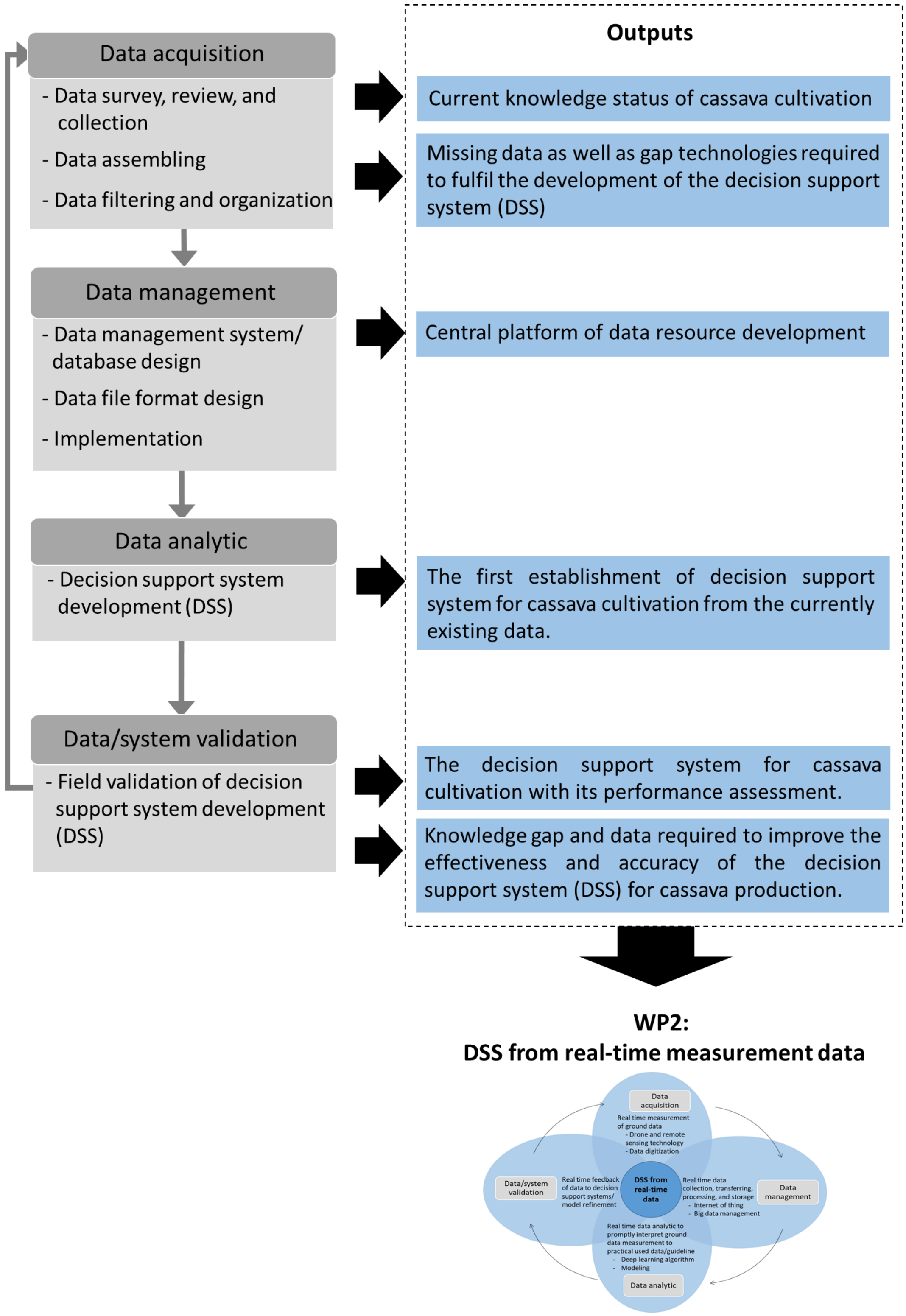


***Figure 9** Overall methodology of work plan 1 (WP1)*

Activities

1. Data acquisition

This part can be divided into 3 steps: 1) data survey and review, 2) data collection, and 3) data filtering and organization.

All cassava data and the related information that have been studied and accumulated, also in terms of knowledge as well as experience, in individual laboratories will be surveyed and reviewed. The process aims not only to explore data for collection, but also to understand the situation of the existing information for further utilization in DSS development. The data collection will be conducted from weather stations, and the data from the fields, and the data at the single-plant level. The data from weather stations includes humidity, atmospheric temperature, photosynthetically active radiation (PAR), rain precipitation, and wind direction and speed. The data from the fields consist of soil type, soil texture, soil nutrient, soil moisture and soil temperature. The data at the single-plant level mainly consist of cassava physiology data such as weight, height, leaf area, leaf numbers and root distribution.The assembled data will be filtered to discard low quality, statistical outlier, non-associative values, and irrelevant data. The usable data will be classified or clustered into a simple organization that allows us to understand the massive data and facilitate data management in the next part.

2. Data management

The gathered data that include the measurement from multi-levels, multi-platform, and multiple laboratories are massive and always contain high heterogeneity.Data management is thus required to standardize all data for further analysis, and also future data acquisition.The uniform format will be designed to accommodate all data types. Such data file format is basically used to transform the heterogeneous data into a single systematic notation, which is essential for later data arrangement in storing system and analysis. The format may employ geographic information and time (day of year) to link all related information (e.g. soil type, irrigation rate, fertigation (N, P, K) rate,) together. Database or data repository will be developed to support the management of these big data and facilitate the data analytic, a crucial part of decision support systems. This step of data management will lead to the central platform for the project, which potentially uses cloud system or the mature developed system such as Agrimetrics (https://www.agrimetrics.co.uk/).

3. Data Analytic

The data analysis will be carried out based on data resource from the developed data management system. For the first step, the association of each data type will be examined to related the environmental factors, plant response and cultivation treatments together which will then be linked to the produced biomass (also yield and productivity). Each environmental factor will be analyzed and be related to the cassava response in the field or production scale (tons per rai (1,600 sqm)). The relatively simple model of cassava biomass (above ground and storage root) or cassava yield can be built from statistical analysis as the initial model for further adjustment. The focuses of the model are water use efficiency (irrigation) and fertilizer use (fertigation). Besides modeling technique, artificial intelligence based approach may be employed to empower the data analytic of the simple model. Lastly, the model will eventually become a critical part of the so-called first version of the decision support system.

4**. (**DSS**)** System validation

The established decision support system (DSS) will provide the information that would guide the farmer to design the optimized plantation, high yield with low inputs. The performance of system will preliminarily be validated with the field data from the experimental plot (at least 5 rai or 8,000 m^2) in irrigated area. The validation of the system may be extended by using information from various locations of cassava farms of our network farmers. The performance of the DSS system will be assessed against the conventional practice, which is the regular plantation method in that region. The results of this step will allow us to identify the insufficiency of existing data and the required technology for supporting measurement. This information will be provided as points to be improved in further development of DSS for cassava production in WP2.

Timeline: WP1 - Development of decision support system (DSS)

Work plan	Year 1		Year 2		Year 3	
	M1-M6	M7-M12	M1-M6	M7-M12	M1-M6	M7-M12
1. Data acquisition						
- Data survey and review						
- Data assembling and collection						
- Data filtering and organization						
2.Data management						
- Data management system/database design						
- Data file format design						
- Data transformation						
- Central platform of data resource development						
3. Data Analytic						
- Model development						
- Decision support system development (DSS)						
4. (DSS) System validation						
- Design optimized plantation practice based on DSS system						
- Field plantation and ground measurement						
- Assessment of DSS performance						
5. Overall analysis the developed DSS and identify the gap of knowledge (data) as well as required supporting technology						
6. Reporting and documentation						

Expected outputs from WP1

1. The first establishment of decision support system (DSS) for cassava production from the current available data
2. Identification of data required for fulfilling precision farming for cassava production
3. Identification of gap technology towards precision farming for cassava production

Expected outcomes from WP1

1. The first implementation of decision support system (DSS) for cassava cultivation will turn the conventional practice of cassava production into more precise manner. Not only elevating yield, but also increases efficiency of resource (i.e. water and nitrogen fertilizer) use.

2. The new practice will earn more profit to cassava farmers according to the statement "produce more with less".It will create wealth in cassava farming.

3. Increase yield of cassava under the minimized water and nitrogen fertilizer will shift the paradigm of current agricultural practice to be more environmental friendly.

4. The implementation of precision farming in cassava production will secure food as well as carbon source for the growing world population with less threat to natural resources.

5. The precision farming is a promising framework for integrating technology to improve agricultural practice towards sustainable crop production, which will be here demonstrated by cassava crop production case study.

Estimated budget of WP1

WP1 Activities	Budget (THB / 3 years)
1. Data acquisition(Data survey and review, Data assembling and collection, Data filtering and organization) - Researchers (40,000 THB/month x 36 months x 2 persons) – responsible for work in WP1. - Logistics (Honorarium, meeting allowance and transportation)	3,000,000 200,000
2. Data management (Data management system/database design, Data file format design, Data transformation, Central platform of data resource development) - Wage (job-based hiring, or contract-hiring) for data system construction - Logistics (Honorarium, meeting allowance and transportation) - Computing facility rental cost and software license	2,000,000 200,000 1,000,000
3. Data Analytic (Model development, Decision support system development (DSS)) - Logistics (Honorarium, meeting allowance and transportation) - Computing facility rental cost and software license	200,000 1,000,000
4. (DSS) System validation (Design optimized plantation practice based on DSS system, Field plantation and ground measurement, Assessment of DSS performance)	

- Wage (Field experiment) (300 THB/day x 366 days x 5 persons) - Field experiment (plantation and ground measurement) - Logistics (Honorarium, meeting allowance and transportation)	550,000 1,000,000 200,000
5. Overall analysis the developed DSS and identify the gap of knowledge (data) as well as required supporting technology - Logistics (Honorarium, meeting allowance and transportation)	 200,000
6. Reporting and documentation	30,000
Total	**9,580,000**

WP2 Technology development for decision support system (DSS) from real-time data

Objectives

1. To develop real time data acquisition of cassava cultivation using close-range remote sensing technologies (aerial drone imaging and weather station).
2. To develop geoinformation mining data on cassava cultivation
3. To develop artificial intelligent (AI) modeling for automated prediction of cassava cultivation

WP2 summary

WP2, which is related to WP1 with the identification of the technology gap, focuses on the development of the new technology platforms to understand the efficient water and fertilizer use for cassava cultivation. The cutting-edge technologies that will be deployed in WP2 for large-scale cassava fields include integration of small Unmanned Aerial System (sUAS) or Drone, satellite images, and weather micro station for real-time data. WP2 can be divided into three steps. The first step is **data acquisition** using close-range remote sensing technologies. The second step is **data management** using agri-geospatial data. The final step is **data processing** using AI or fitted modeling for linking between the ground data in WP1and the close-range remote sensing data from WP2. After three steps are completed, the agri-geospatial data will be extended to further step (the combination of WP1 and WP2) (the overall process is shown in Figure 10, 11). Lastly, WP2 will be moved to WP1 (Fig 8 Workflow of work plans) and WP3 respectively.

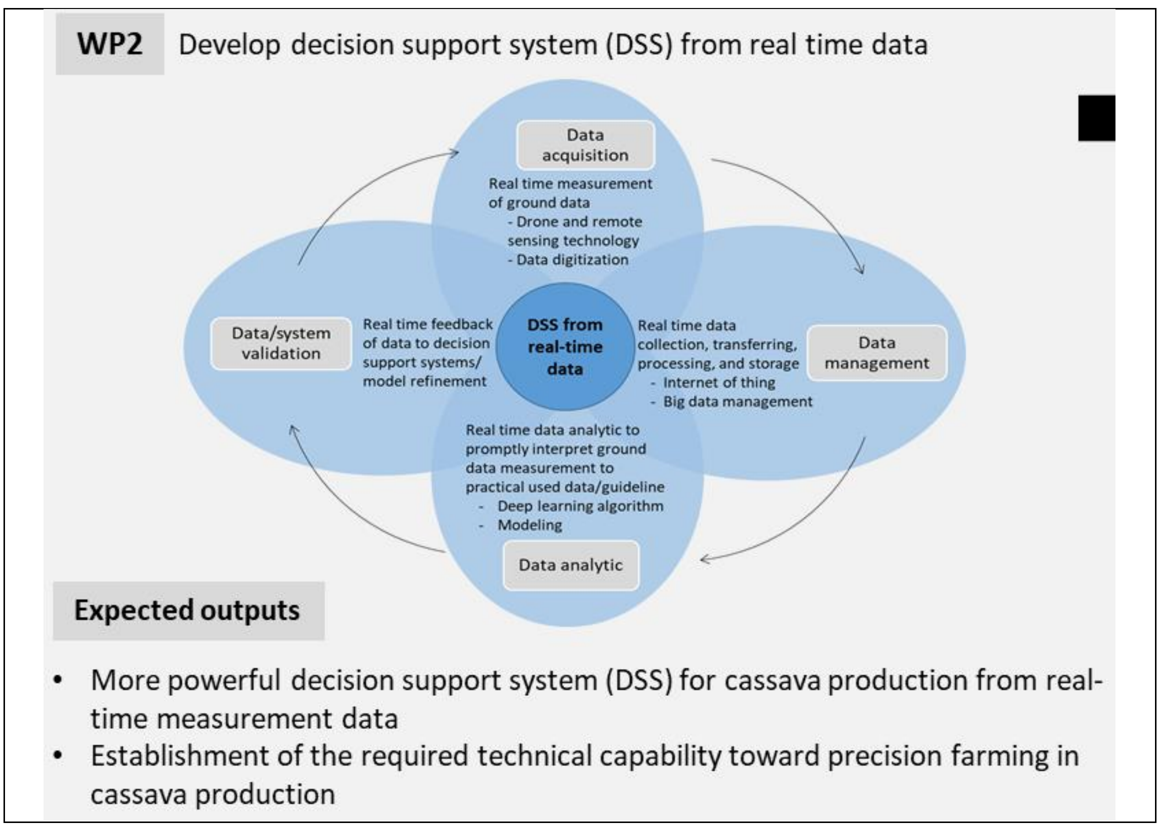


Figure 10. *Overall methodology of work plan 2 (WP2)*

Figure 11. *System arhitecture of WP2. No.1 is Data acquisition using aerial drone and multiple-camera. No.2 isdata management using agri-geospatial data format* (*data mining*). *No.3 is data analytic and DSS from real time data. No.4 is the future of precision agriculture for semi-automated agriculture management.* (*Revised from* *https://pix4d.com/product/pix4dfields*), *(Pablo et al., 2014).*

Activities

1. **Data acquisition: using close-range remote sensing technologies**

In this step, the study applies the close-range remote sensing technologies and the real time measurement. The close-range remote sensing includes aerial drone, which consists of payload of multi-cameras such as visual, multiple, hyper-spectral, and thermal sensors for spectral information. The cassava data collection and the frequency setup will be conducted from aerial drone under the conditions of cassava cultivation known in the cassava crop calendar. Next, the data will be merged with the data from weather stations from WP1 using geotag and time syncing. The usable data will be transformed to geoinformation data format in order to facilitate data management in the next part.

2. Data management: using agri-geoinformation data

The real-time collected data, which include the measurement of multi-levels (aerial drone and ground sensing) and multi-platforms (aerial drone and weather station) are always massive and contain high heterogeneity. This study applies the geoinformation platform to resolve this problem. The geoinformation platform will design the multi-architecture of GIS including raster and vector standard formats such as .geotiff, .shp. Then, the agri-geodatabase portal will be created and can real express real-time data in the mapping online by general web browsers.(https://pix4d.com/product/pix4dfields/), (http://www.precisionhawk.com/agriculture).

3. Data analytic and DSS from real-time data

In the term of data processing, the project focuses on the relationship between the ground (WP1) and close-range remote sensing data. The first step will be performed agri-geospatial data mining by the calculation of the vegetation indexes from close-range remote sensing of aerial drone such as NDVI (Normalized Vegetation Index), VARI (Visible Atmospherically Resistant Index), ENDVI (Enhanced Normalized Different Vegetation Index), OSAVI (Optimized Soil Adjusted Vegetation Index), RDVI (Renormalized Different Vegetation Index) andVARI (Vegetation Adjusted Reflectance Index), Soil-moisture, 3D and Textural information. The second step is to determine the GIS prescription and zoning boundary of cassava cultivation such as soil-moisture, fertilization concentration, healthy and above and underground yield layers of cassava. The empirically mathematic models, the key knowledge from WP1, and the AI machine learning will be developed for precision cassava mapping. The final step is to establish the agri-geo information data by the terms of newly real-time measuring and managing, which will be display in the agri-geodatabase portal.If the overall process has been done the WP2 will be moved to WP1 (Fig 8 Workflow of work plans) and WP3 respectively.

Timeline: WP2–Technology development of decision support system (DSS) from real-time data

Work plan	Year 1		Year 2		Year 3	
	M1-M6	M7-M12	M1-M6	M7-M12	M1-M6	M7-M12
1. Data acquisition: using close-range remote sensing technologies			↔	↔		
• Drone and multi-camera setup			↔			
• Flight planning for data collection			↔			
2. Data management: using agri-geo information data			↔	↔	↔	↔
• Develop of agri-geo information platform			↔	↔	↔	
• Develop of agri-geo information portal (online mapping)				↔	↔	↔
3. Data processing: using AI for linking between ground and close-range remote sensing data			↔	↔	↔	↔
• Develop data classification model using AI, learning machine from veg. Indexes, weather station or other.			↔			
• Model validation and refinement					↔	
• Publishing to agri-geo information portal (online mapping)					↔	↔
4. Overall analysis the technology developed DSS real time and prediction data: identify the key technology and minimize complex technology deployment to support technology transfer in WP3						↔
5. Reporting and documentation				↔		↔

Expected outputs from WP2

1. Establishment of appropriate algorithm of aerial drone capturing for real-time measurement data in cassava cultivation
2. Establishment of agri-geospatial data for real-time management data in cassava cultivation.

Expected outcomes from WP2

1. The first implementation of agri-geospatial data from real-time measuring and managing for precision cassava cultivation

Estimated budget of WP2

Activities	Budget (THB / 3 years)
WP2	
1. Data acquisition: using close-range remote sensing technologies (Project planning, Drone and multi-camera setup, Data survey and review, Data assembling and collection, Data filtering and organization)	
- Researchers (40,000 THB/ month x 24 months x 2 persons) – responsible for work in WP2.	1,920,000
- Researchers assistance (20,000 THB/month x 36 months x 2 persons) – responsible for work in WP2.	1,440,000
- Logistics (Honorarium, meeting allowance and transportation, field collection)	1,500,000
- Drone, Multi-camera (Visual, Multispectral, Thermal Cam) and accessories rental cost. (1 set full option)	3,000,000
- Weather station rental cost. (2 sets full option)	800,000
- Photogrammetry software and computer rental cost.	1,000,000
2. Data management: using agri-geoinformation data (agri-database platform)	
- Wage (job-based hiring, or contract-hiring) for development of agri-database construction.	2,000,000
- Logistics (Honorarium, meeting allowance and transportation)	300,000
- Computing facility rental cost and software license	1,000,000
3. Data processing: using AI for linking between ground and close-range remote sensing data	
- Wage (Field accuracy assessment) (300 THB/day x 150 days x 5 persons)	225,000
- Logistics (Honorarium, meeting allowance and transportation)	300,000
4. Overall analysis the technology developed DSS real time and prediction data: identify the key technology and minimize complex technology deployment to support technology transfer in WP3	
- Logistics (Honorarium, meeting allowance and transportation)	200,000
5. Reporting and documentation (Map printing, Documents)	200,000
Total	**13,885,000**

WP3 Capacity building of precision farming for Thai cassava farmers

Objectives

1. To implement the precision farming with the DSS platform utilization on the real cassava fields in Thailand
2. To increase the number of precision cassava farmers as the leading farmers for their local communities
3. To improve the accuracy, the performance, and the utilization of the DSS platform via the feedbacks from the real cassava farmers

WP3 summary

WP3 is the process of the technology transfer to the users. The established DSS technology platform from WP1 will be deployed to the target groups including real cassava farmers. Two main focuses of WP3 are to provide the DSS platform as a smart farming tool for real farmers and to receive the feedbacks from the farmers for further improvement of the DSS platform. First, we identify the target groups (listed below), which are the intended users of our technological platform. The users will be trained on the DSS platform utilization, and the application of the DSS platform will be demonstrated in our cassava fields. The users are allowed to access the DSS platform any time during the entire WP3 period and are strongly encouraged to apply the DSS platform to their own real cassava fields. The data such as cassava yield and the feedbacks from the users such as features of the DSS platform, functionalities, and platform interface will be the crucial input to further develop the DSS platform.

Target groups

1. **Cassava farmers** – the cassava famers can be categorized into three groups

    i. The farmers already know about smart farming and are eager to smart farming tools to improve their productivity. They will be willing to learn the DSS platform and are very likely to apply the DSS platform in their fields. This group will be our network farmers.

    ii. The farmers know about smart farming but are reluctant to apply smart farming tools to their fields. This group needs verification on the real cassava fields before they decide to invest their time and their resources to utilize the DSS platform. With the results on our demonstration fields, they are like to be convinced and to use the DSS platform in their fields.

    iii. The farmers do not know about smart farming. The aim for this group is to open their perspectives on smart farming with the hope to convert them to category i) or ii).

2. **Officers and staffs from the government-affiliated and private organizations** e.g. Department of Agriculture, Office of the Digital Economy, Thai Cassava Development Center, and universities – the officers can either apply the DSS platform to their own demonstration fields or can expand the DSS platform to their known communities or the cassava farmers that they are working with.

3. **Private sectors that are currently working on cassava yield improvement** – the private sectors include cassava companies and cassava product (e.g. starch, ethanol) companies that own large-scale fields.
4. **Private sectors that aim to promote smart farming** – several companies have the campaigns to promote the smart farming practice to young or new generation of farmers.

Activities

1. **Workshops and demonstration with the target groups** – the workshop for each target group will emphasize on different aspects.
   i. For the cassava farmers, the workshop will focus on two aspects. The first one is the utilization and the simplicity of the DSS platform, which will allow the farmers to quickly learn the platform with minimum required time. The users will learn about how to access and use the DSS platform, how to use the information from the DSS to grow cassava in their fields, and how to collect the field data after they use the DSS.The data will be transferred back to us as an input for WP1. The second one is the demonstration on our cassava fields with the DSS platform utilization. We will show the translation of the DSS information into the practice in the fields. The results from the demonstration will convince the undecided farmers to consider using the DSS platform in their own fields.
   ii. For the officers and staffs from the government- affiliated and private organizations, the workshop will focus on the fundamentals and the utilization of the DSS platform, which will allow them to effectively instruct and communicate with the farmers in the communities about the DSS platform. The demonstration in the field will also be a part of the workshops.
   iii. For private sectors that are currently working on cassava yield improvement, the workshop will focus on the extension and the cover of the DSS platform to large- scale cassava fields. The emphasis will be on how the DSS platform can boost the productivity of the companies.
2. **Meetings and collaboration with private sectors** – in the case of private sectors that aim to promote smart farming, meetings for collaboration should suffice in order to convince them on the importance of the DSS platform as a critical tool for smart farming. If the collaboration is successful, we can recruit new generation cassava farmers through the companies' campaign and increase the number of the precision cassava farmers.
3. **Communication via social media channels** – communication channels are required for following up and feedback giving from the users. We can take advantage of the well-established channels of social media such as Facebook and Line to send the information and the updates from the users. Other communication channels such as helpdesk, e-mail, and phone call are certainly included. All of the feedbacks from the users will be transferred back to us as an input for WP1.

Expected outputs from WP3

1. Utilization of the DSS platform and technology adaptation from the users
2. User feedbacks for the DSS modification and improvement in the future
3. Improved DSS platform based on the data and the feedbacks from the real cassava farmers

Expected outcomes from WP3

1. Increased number of precision cassava farmers as the leading farmers for their local communities
2. Knowledge sharing via two-way discussion between the DSS platform developer team and the users, the workshops between us and the users, and the communication for the entire project time period.
3. Building of awareness on the DSS platform and its application via the workshops
4. Raised awareness on the importance of efficient usage of resources (water and fertilizer) and the importance of smart farming for Thai cassava farmers
5. Demonstration can be extended to other crops in Thailand and to cassava in other countries

Timeline: WP3- Capacity building

Work plan	Year 2		Year 3	
	M1-M6	M7-M12	M1-M6	M7-M12
1. Technology transfer to the target groups	↔	↔	↔	↔
- Preparation of demonstration fields	↔		↔	
- Target groups identification and advertisement	↔			
- Workshop design and arrangement	↔			
- Workshops with the target groups	↔	↔	↔	↔
- DSS platform utilization on the demonstration fields	↔	↔	↔	↔
- Meeting with the target groups	↔	↔	↔	↔
2. Collaboration and communication with target groups	↔	↔	↔	↔
- Helpdesk, troubleshooting, and consultation				
3. Obtaining data and feedback for DSS improvement		↔	↔	↔
- Data and feedbacks from the users		↔	↔	
- Analyze the results from the demonstration fields			↔	↔
- Propose the potential improvement for the DSS platform				↔
4. Reporting and documentation		↔		↔

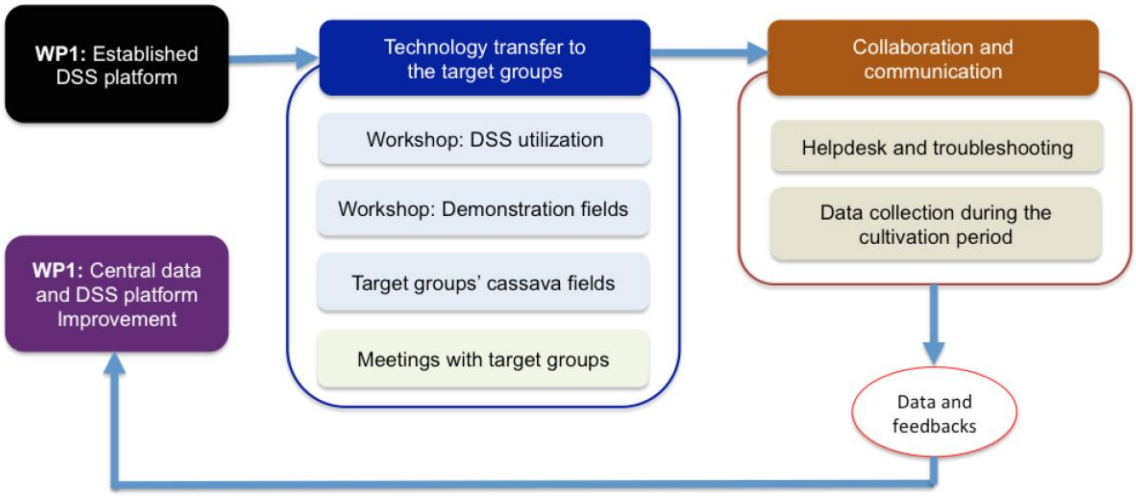


***Figure 12** Overall methodology of work plan 3* (*WP3*)

Proposed business model

The business model is required for sustainable operation in the long-term run. Below are some ideas.

1. Self-sustaining community of users – at the beginning stage e.g. the first few months after the workshops, the users might still need some help and might have some questions. Active communication between the helpdesk team and the users will thusly be the key to the success of the technology utilization and adaptation. Hopefully, as the number of users is expanding, some of the questions will be answered and discussed among the users, resulting in a self-sustaining communication.

2. Funding or financial support can come from several sources such as government funding, subsidy by the government, and licensing or commercialization of the DSS platform

Estimated budget of WP3

WP3 Activities	Budget (THB / 3 years)
1. Technology transfer to the target groups	
- Preparation of demonstration fields (labor cost, breeding materials, irrigation system, fertilizers, etc.)	1,000,000
- Target groups identification and advertisement (via electronic media, social media, and all possible channels)	100,000
- Workshop design and arrangement	100,000
- Workshops with the target groups (location fee, food, printed materials, traveling cost, etc.)	500,000

- DSS platform utilization on the demonstration fields (arrangement with Bioscience, expert fee, additional materials for the fields, etc.)	1,000,000
- Meeting with the target groups (meeting arrangement, location, foods, traveling cost, etc.)	300,000
2. Collaboration and communication with target groups	
- Helpdesk, troubleshooting, and consultation (setting up communication channels, labor cost, etc.)	500,000
3. Obtaining data and feedback for DSS improvement	
- Data and feedbacks from the users (feedback collection, labor cost, etc.)	200,000
- Analyze the results from the demonstration fields (labor cost, etc.)	200,000
- Propose the potential improvement for the DSS platform (meeting arrangement, etc.)	100,000
4. Reporting and documentation	20,000
Total	**4,020,000**

References

Abass, A. B., Awoyale, W., Alenkhe, B., Malu, N., Asiru, B. W., Manyong, V., & Sanginga, N. (2018). Can food technology innovation change the status of a food security crop? A review of cassava transformation into "bread" in Africa. *Food Reviews International*, *34*(1), 87-102.

Cassava Consumption by Country, ChartsBin.com, viewed 15th March, 2018, http://chartsbin.com/view/34825

FAO, 2016. FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, Italy

Montagnac, J. A., Davis, C. R., & Tanumihardjo, S. A. (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. *Comprehensive reviews in food science and food safety*, *8*(3), 181-194.

Prakash, A., (2005). Cassava: International market profile. *Competitive Commercial Agriculture in Sub–Saharan Africa (CCAA) Study*. Trade and Markets Division, Food and Agriculture Organisation of the United Nations.

Sackey, I. S., & Bani, R. J. (2007). Survey of waste management practices in cassava processing to gari in selected districts of Ghana. *JOURNAL OF FOOD AGRICULTURE AND ENVIRONMENT*, *5*(2), 325.

Sánchez, A. S., Silva, Y. L., Kalid, R. A., Cohim, E., & Torres, E. A. (2017). Waste bio-refineries for the cassava starch industry: New trends and review of alternatives. *Renewable and Sustainable Energy Reviews*, *73*, 1265-1275.

Veiga, J. P. S., Valle, T. L., Feltran, J. C., & Bizzo, W. A. (2016). Characterization and productivity of cassava waste and its use as an energy source. *Renewable Energy*, *93*, 691-699.