CHAPTER I

INTRODUCTION

1.1. Background

Agriculture has become an important part of the economic sector of countries in the Southeast Asian region and a significant contributor to their gross domestic product (GDP). One of them is Thailand, an exporter of agricultural products such as rice, tapioca, rubber, sugar, and vegetables (International Trade Administration, 2022). The agricultural sector remains a crucial component of the Thai economy despite its recent efforts to diversify. For example, Thailand is listed as one of the world's largest exporters of rice, sugar, and tapioca products (Pipitpukdee et al., 2020; Ratanawaraha et al., 2020; Thaichareon & Stapornchanchai, 2023). As one of the largest global food producers, Thailand needs accurate information to support appropriate actions in managing its agricultural land and potential challenges.

Thailand's rice sector faces significant challenges in maintaining its productivity, including low yields, labor limitations, and water resource constraints. Given the vital role of climate in agriculture, Thailand's reliance on rain-fed farming systems exposes the sector to various operational constraints. The impact of climate change on rice productivity and continued population growth poses a threat to food security. It has prompted rice producers and the Thai government to implement strategies to adapt production methods to global climate change (Sinnarong et al., 2019). Addressing the complexity of this problem requires a comprehensive approach that combines cutting-edge technologies with sustainable agricultural practices. The accuracy and timeliness of information on rice yield potential are crucial in ensuring food, climate, and water security (Moukomla et al., 2023).

Remote sensing offers technology-based agricultural management to provide more precise monitoring conditions, predictive results of water assessment soil properties maps, and risk management of the agricultural process itself (Benami et al., 2021; Weiss et al., 2020). The use of remote sensing technology in conjunction with climate data shows significant potential in revolutionizing crop production by providing farmers with in-depth information on the characteristics of the land they manage and the conditions essential for optimal growth of crops.

Plant growth and development patterns can be measured using phenology metrics, which involves assessing the timing and patterns of plant growth and development in a seasonal context. These phenology metrics provide an understanding of plant growth and development phenomena and the influence of environmental factors (Orusa et al., 2023). Within this scope, there are several commonly used phenological indicators. One of the most frequently adopted is the Normalized Difference Vegetation Index (NDVI) due to its ease of use and interpretation (Spadoni et al., 2020). NDVI measures the greenness of vegetation by referring to the difference between feature values in the red and near-infrared spectral bands, which distinguishes vegetation land cover types amidst the diversity of existing land cover types. Another vegetation index used is the Enhanced Vegetation Index (EVI), which directly corrects reflections from the red band by considering reflections from the blue band, as well as accounting for the residual influence of atmospheric contamination, such as aerosols, and also variations in reflections from background soil and canopy. In addition, the Land Surface Water

Index (LSWI) is used to observe an area's vegetation moisture and groundwater, which is useful for detecting the phenological stages of a cropping area (Kania Sari et al., 2010). The Bare Soil Index (BSI) is also used to detect periods of bare soil, which can effectively characterize the mineral content of soil in agricultural areas (Ni et al., 2021).

In recent years, rice phenology monitoring using satellite and remote sensing technologies has advanced significantly, with researchers leveraging machine learning and data analysis techniques to enhance accuracy and efficiency. Ariza (2019) showcased the effectiveness of machine learning in estimating rice growth phases, achieving F-1 scores above 0.94 with random forest, support vector machine, and gradient boosting trees, and attaining a high accuracy rate of 94.7% in identifying harvested areas. In the study of Ni et al. (2021), several indices were used to identify rice phenology, namely BSI, LSWI, GCVI, NDVI, EVI, and PSRI, resulting in an enhanced pixel-based phenological feature composite method (Eppf-CM) for rice mapping, achieving an overall accuracy higher than 0.98 when compared with field survey data. Sukmono et al. (2020) utilized the Enhanced Vegetation Index (EVI) derived from Landsat 8 imagery to classify rice growth stages, observing maximum EVI values in paddy fields ranging from 0.4 to over 0.9. Earlier, Kania Sari et al. (2010) employed EVI and LSWI derived from MODIS data to identify key dates within the rice growth cycle, achieving root mean square errors between 851 Ha for monthly data and 2433 Ha for annual data.

Despite recent advancements, current approaches still face several significant limitations, such as dependence on a single vegetation index, reliance on lower-resolution satellite imagery, and the absence of an integrated approach that combines multiple indices with advanced machine learning techniques. These limitations highlight the need for a more comprehensive approach to rice phenology monitoring. Future studies could address these challenges by integrating multiple vegetation indices with modern machine learning algorithms and utilizing high-resolution satellite data, such as Sentinel-2, offering a deeper and more accurate understanding of rice growth dynamics.

Remote sensing and artificial intelligence (AI) technologies integrate big data to accurately predict and determine the status of crops on the ground. This provides an opportunity to address future challenges in nutrition in agriculture. Systems enriched by the application of artificial intelligence (AI) can deliver optimized accuracy with minimal resource usage in performing tasks that are large in scale, high in power intensity, and time-consuming. This is intended to address several challenges that have significant impacts, including climate change, decreased water availability for irrigation purposes, increased production costs, and an overall reduction in labor in the agricultural sector (Jung et al., 2021).

This research aims to develop an integrated approach for monitoring rice crop phenology using multiple vegetation index signatures, including NDVI, EVI, LSWI, and BSI, combined with machine learning techniques. Integrating multiple vegetation indices allows for a more comprehensive analysis of rice plant growth. Three models will be constructed, namely Random Forest, SVM, and XGBoost models, where the selection of these models is based on their ability to handle complex data and produce accurate predictions. The sentinel-2 satellite image dataset is utilized as a data source for extracting vegetation index values, providing advantages in terms of spatial and temporal resolution sufficient for monitoring crops. Implementing this approach is useful in obtaining information about agricultural conditions, especially in rice fields. The resulting information on rice crop phenology is expected to support decision-making related to rice plant management, including optimization of planting schedules, estimation of crop yields, and early detection of plant growth problems.

1.2. Identification of Research Problem

Based on the background that has been described, some of the problems that can be identified are as follows:

1. Current rice monitoring systems rely heavily on single vegetation indices and lower-resolution satellite imagery, limiting their effectiveness in providing comprehensive crop analysis.
2. Thailand's rice sector faces multiple challenges, including low yields, labor shortages, and water resource constraints. These challenges are amplified by climate change impacts and require better monitoring and management solutions.
3. Existing approaches lack integration between multiple vegetation indices (NDVI, EVI, LSWI, and BSI) and advanced machine learning techniques, which could potentially provide more accurate and comprehensive analysis.
4. There is a critical need for accurate and timely information to support agricultural decision-making, particularly in optimizing planting schedules, estimating crop yields, and early detection of growth problems.
5. There is a gap in monitoring systems that can effectively track the growth stages of rice crops while utilizing high-resolution satellite data (Sentinel-2) for precise analysis.

1.3. Research Scope

To focus the research and ensure the achievement of the objectives within the time and resources available, certain boundaries were established as follows:

1. This research will focus on analyzing crop phenology limited to rice.
2. The data collection location will be limited to Chachoengsao Province, Thailand.
3. The satellite image that will be used to analyze rice phenology is the Sentinel-2 satellite image.
4. This research will examine three main phases in the crop phenology cycle, namely, Start of Season (SOS), Peak of Season (POS), and End of Season (EOS).
5. This research focuses on developing machine learning methods using Random Forest, Support Vector Machine (SVM), and XGBoost model.
6. Model performance evaluation is confined to several evaluation metrics, specifically accuracy, precision, recall, and f-1 score.

1.4. Research Questions

Based on the research questions that have been determined, the research question is formulated as follows:

1. How can Sentinel-2 satellite-derived vegetation indices (NDVI, EVI, LSWI, and BSI) be used to characterize the three main phenological stages (SOS, POS, and EOS) of rice crops in Chachoengsao Province, Thailand?
2. How do different machine learning models (Random Forest, SVM, and XGBoost) perform in classifying rice phenological stages using multiple vegetation indices from Sentinel-2 data?

1.5. Research Objectives

Based on the research questions that have been described, the objectives of this study are as follows:

1. To analyze and characterize rice phenological stages (SOS, POS, and EOS) using multiple vegetation indices (NDVI, EVI, LSWI, and BSI) derived from Sentinel-2 satellite imagery in Chachoengsao Province, Thailand.
2. To develop and evaluate the performance of different machine learning models (Random Forest, SVM, and XGBoost) in classifying rice phenological stages using the extracted vegetation indices.

1.6. Research Benefits

This research is expected to provide benefits, both theoretically and practically, as follows:

1. Theoretical Benefits

   This research is expected to significantly contribute to the development of a scientific understanding of the relationship between various vegetation indices and rice phenological stages, as well as evaluate the effectiveness of various machine learning approaches in monitoring plant growth dynamics. In addition, this research will expand insights into the application of remote sensing and machine learning integration in agriculture, as well as the development of an optimal vegetation index fusion methodology to improve the accuracy of crop phenology change detection.
2. Practical Benefits

   This research is expected to be a useful source of information for farmers and land managers in making more timely and effective decisions related to rice crop management. With accurate phenological information, this research also has the potential to support the optimization of agricultural practices, such as irrigation, fertilization, and pest control, thereby increasing productivity and efficiency in farmland management.