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Reconstruction of MODIS EVI Time Series to Map Maize Cropping Patterns in Sloping Areas: A Case Study in Son La of Vietnam

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Abstract

Mapping maize cropping patterns and acreage is important to many stakeholders in Vietnam where official statistical data is not up-to-date. This study demonstrates the use of Savitzky - Golay and Support Vector Machine algorithms on a time series of Moderate Resolution Imaging Spectroradiometer Enhanced Vegetation Index data (2003 - 2018) to detect and map the maize cropping patterns on the sloping area of Son La province of Vietnam. The method was able to map the spatial distribution of maize cropping patterns in areas where cultivated acreages were highly fluctuated recently, with an overall accuracy of 81.6%. Districts' estimated maize acreages also show a good agreement with the official data at r = 0.75. Our findings suggest that a further improvement of the maize cropping pattern map can be made when higher spatial resolution remote sensing data are available and better presentative training samples for the whole region could be considered.

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1. Introduction

Maize (*Zea mays*) is an important cash crop in Vietnam. According to the latest statistical data by 2021 the total maize cultivated area for the whole country was approximately 903 thousand hectares. Of which 8,64% (78 thousand hectares) was contributed from Son La, making it the second largest maize-producing province (Government Statistic Office, 2023). Currently, maize is the second largest annual crop in planted regions of the North-Western provinces of Vietnam. The prevailing cultivation practice of maize in these areas is monoculture, which involves planting maize exclusively on the upland slopes (Hoang *et al*., 2017) [12]. Son La was reported as a mountainous province where about 80% of arable land is sloping and reserved for maize, rice, industrial, and fruit crops (Dang and Nguyen, 2020) [8].

It would be thought that there is a connection between production level and low productivity in countries with underdeveloped statistical and production information systems (Burke and Lobell, 2017) [4]. In the context of small and fragmented maize production, it is difficult and expensive to accurately assess the production reality by traditional methods (Wang *et al*., 2020) [18]. Along with the rapid and strong development of space technology, remote sensing technology has been successfully applied in various aspects of agriculture, especially in evaluating reality and forecasting crop productivity (Weiss *et al*., 2020) [19]. The application of remote sensing technology for agricultural production management is one of the fields that has been very successful in many countries worldwide (Gao, 2021) [10]. Modern remote sensing techniques, especially the development of optical remote sensing with a high resolution of LandSat/Multispectral Scanner System, Thermatic mapper, and Spot have been reported to provide investigative data, analyze and evaluate in detail and accurately the continental surface.

More specifically, National Oceanic and Atmospheric Administration/ Advanced Very High Radiometer and Moderate Resolution Imaging Spectroradiometer (MODIS) satellites have wide scanning, high temporal resolution, and respond quickly and promptly to information for large areas. Radar remote sensing allows independent observation of all weather conditions, which is a potential source of data suitable for mapping production reality and predicting crop yields. Using remote sensing technology and Geographic Information System (GIS) has brought remarkable effects to the economy (Cracknell, 2018) [1]. Although many studies have suggested that remote sensing and GIS have changed the quality and quantity of scientific research on agriculture, changing research scope, research content, nature, and agricultural methodology. However, the application of remote sensing technology to evaluate the reality and productivity of crops is still lacking. Recently, we mapped maize cropping patterns of the steppe area in Center Highland (Nguyen *et al*., 2020) [15]. In addition to this, we reported on the reconstruction of the MODIS Enhanced Vegetation Index (EVI) time series to map maize cropping patterns in sloping areas with a case study in Son La, Vietnam.

2. Method

Study sites

According to the Ministry of Natural Resource and Environment (2022), Son La is one of the mountainous and border provinces in Northwest Vietnam with 1,410,983 hectares of natural land, of which the agricultural land is 1,056,751 hectares with 85.3 thousand hectares of maize production. Son La is the second-largest maize-produce province, but the average yield is as 88% as the national average (49.3 tons ha^{-1}). Son La has a typical climate of tropical monsoon climate with a humid, rainy hot summer and dry cold winter. The annual average temperature is 21. 9ºC with the highest monthly average temperature of 28.3ºC in May, and the lowest of 14.6ºC in January. Frost usually occurs from December to January. Sunshine hours are lowest in January (90.6 hours) and highest in May (218.6 hours). The average relative air humidity is 78% with the lowest (74%) in March and the highest (88%) in July. The average annual rainfall is 1,575.6 mm, unevenly distributed. Rain rarely occurs in early Spring (February to March), which leads to moisture deficiency for plant growth and development, especially for annual plants with shallow roots and poor drought tolerance, such as maize. The rainy season starts from June to September with 80% of annual rainfall. During these months, heavy rain often leads to erosion, leaching the soil and nutrients, and reducing the crop fertilizer use efficiency.

Mapping method

Figure 1 presents the overall approach of mapping the maize cropping patterns as following works

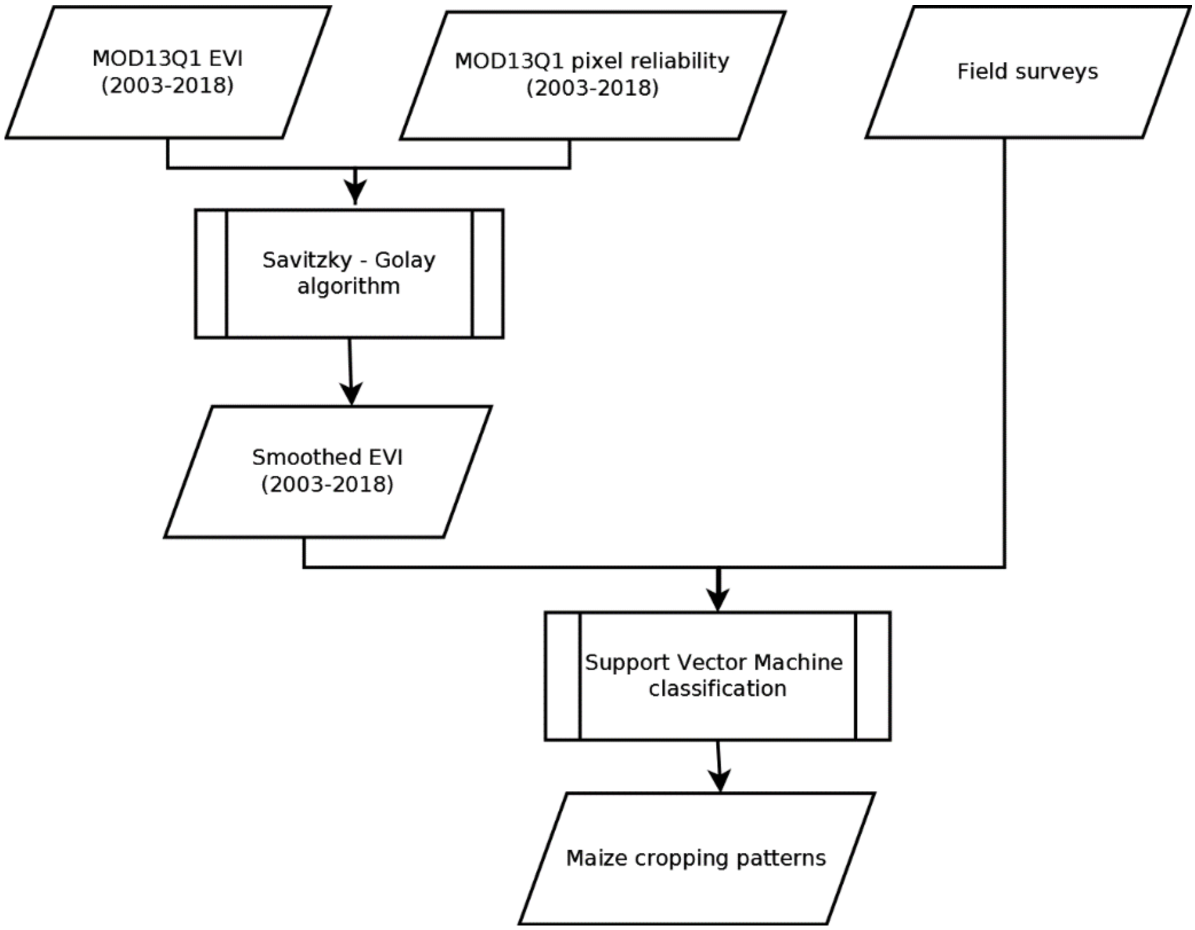


Fig 1: Mapping approach of the spatial distribution of maize cropping patterns

MODIS data collection

MOD13Q1 is a 16-day global product with 250m spatial resolution and is atmospherically and geographically correct. To detect the maize cropping patterns, the MODIS data from 2003 through 2018 was used. Subset data can be ordered and downloaded directly at https://lpdaacsvc.cr.usgs.gov/appeears. The MOD13Q1 EVI and pixel reliability were then extracted and organized before the application of the Savitzky-Golay (SG) algorithm. The pixel reliability is a quality control index, which summarizes pixel quality as a ranking system with 8-bit integer values stretching from -1 to 3 (https://lpdaac.usgs.gov/products/mod13q1v006/#documentation). A value of 0 was decided to be used as a scan to eliminate unsuitable pixels in the original EVI data before they were used as inputs to the SG algorithm. All the MOD13Q1 data were pre-processed and organized as yearly stacks with 23 layers each in Interactive Data Language (IDL) programming.

Field survey data

Field sites of maize growing areas including provinces Moc Chau, Mai Son, and Thuan Chau were selected in proportion to the total maize area of each district. For statistical purposes, 600 randomly selected maize-growing households in each district were visited. The interview information of maize growers included the geographical location of the visited maize field (recorded by a handheld GPS device), and the geographical location of other neighboring fields/ vegetation. The GPS information was recorded in the middle of the field to ensure the error of the GPS device. For maize fields, all corners of the field were collected. Fields selected in an area where maize is grown with high homogeneity (>80% maize cover), the area was at least 250m x 250m to be compatible with the spatial resolution of satellite images. The information about maize crops, neighboring crops, and maize cultivation methods was interviewed and carefully recorded. Statistical data on the total maize area by district was collected for comparison with the mapping results.

Savitzky-Golay algorithm

The SG algorithm was conducted according to the method of Chen *et al*. (2024) and expressed as follows:

$$Y_j^* = \frac{\sum_{i=-m}^{i=m} C_i Y_{J+i}}{N}$$

In the SG filter equation above, Y represents the original EVI values, Y^* represents the computed EVI value, Ci represents the coefficient for the ith EVI value of the filter (smoothing moving window), and N represents the number of convoluting integers, which is equal to the size of the smoothing window $(2m+1)$ points, where m is the half-width of the smoothing window. The values of Ci can be obtained from Steinier *et al*. (1974).

In this study, the SG algorithm was written in IDL language and performed three steps as follows: The first step was to start estimating the multi-temporal EVI value based on the seasonal value law between the target pixel and its neighbors. This allows for the grouping of pixels close together in the same vegetation type, interpolating missing values due to poor pixel quality, and maintaining the variation of EVI values according to the growing season of each vegetation.

The second step was to construct a new temporal multitemporal EVI value set by integrating the original EVI time series of the target pixel with the EVI time series just generated from the first step.

The third step was to build an interpolation model that allows the best asymptotic to the newly generated EVI multi-time values of the pixel by self-adjusting weights based on the above value of EVI.

Support Vector Machine classification

The Support Vector Machine (SVM) seeks to find the optimal separating hyperplane between classes by focusing the training cases lying at the edge of the class distribution, the support vectors, with the other training cases effectively discarded (Foody and Mathur, 2004; Mercier and Lennon, 2003; Belousov *et al*., 2002; Brown *et al*., 2000) [9, 14, 2, 3]. To train the SVM classifier, a set of training samples covering broad vegetation types was taken. Using the information provided from one-third of the GPS field surveys for maize areas and the historical high spatial resolution on Google Earth Pro, the SG smoothed EVI profiles for each major vegetation cover type of Son La can be identified. The SVM classification was carried out using the SVM built-in function under the supervised classification group in Environment for Visualizing Images (ENVI) software.

The accuracy assessment of mapping the maize cropping pattern was assessed only for maize-cultivated areas by considering the agreement in percentage between the field data and the map units. The validation was conducted using the rest of the field survey data, excluding the ones that had been previously used as training samples for SVM. The official statistics of the maize cultivated area in each district were used to compare with the area estimated by the SVM classifier on SG smoothed EVI data. This correlation coefficient (r) was verified by Statistic 8.0 software.

3. Results and discussion

The distribution map of maize growing areas detailed in Figure 2 shows that the highest maize area is grown in Muong La province followed by Mai Son, Phu Yen, Yen Chau, and Moc Chau districts. According to official statistical data, maize is mostly grown in Mai Son, Moc Chau, Yen Chau, Phu Yen, and Muong La. By both data, Sop Cop and Son La city were fewer maize-growing districts. The results of the analysis of maize area in the districts by SVM had a higher value (22.6%) than the annual statistics by the traditional method. The largest difference in maize area recording by the two methods was in data from the Sop Cop, Quynh Nhai, Muong La, Bac Yen, and Phu Yen provinces (Figure 3). However, these two statistical values had a close correlation with a coefficient of r = 0.75** (Figure 4).

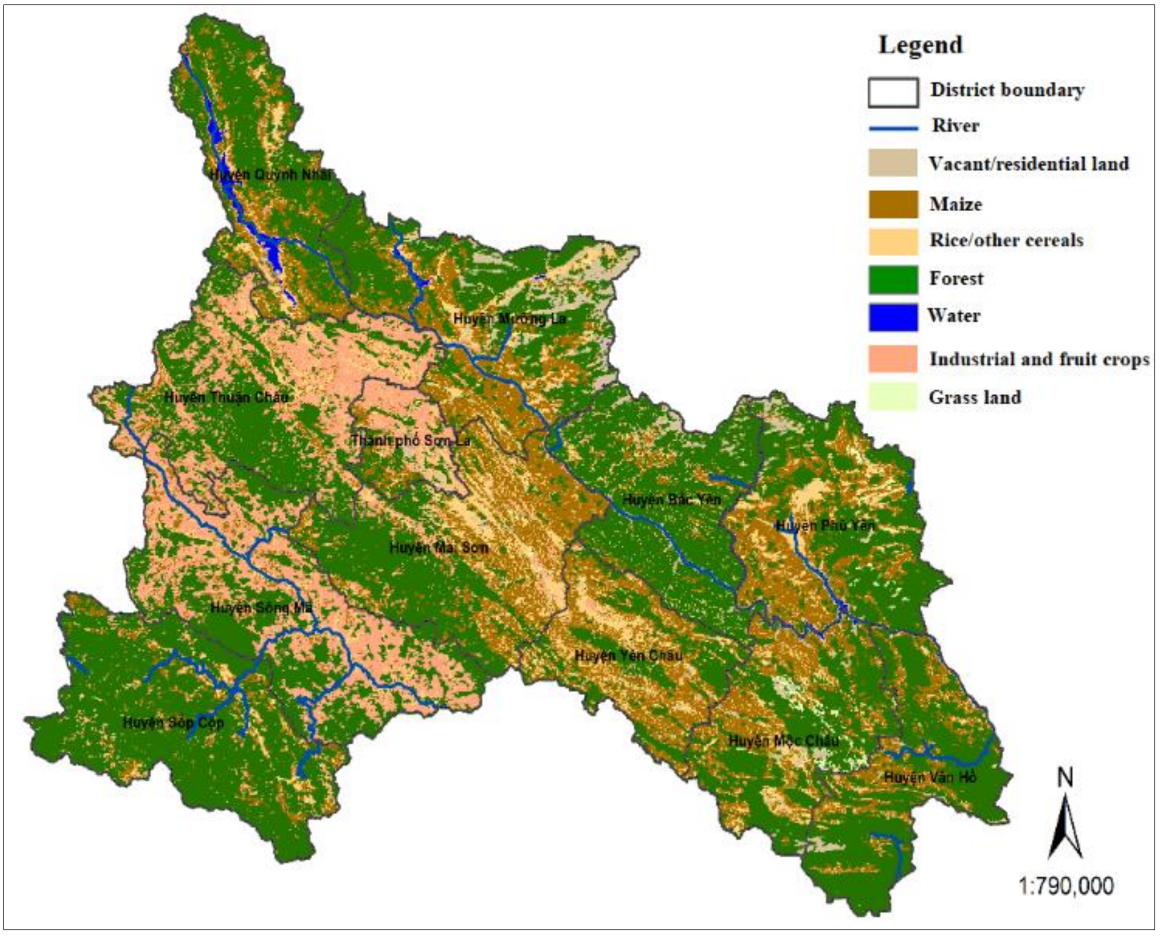


Fig 2: The distribution of maize and other crops in Son La based on satellite image

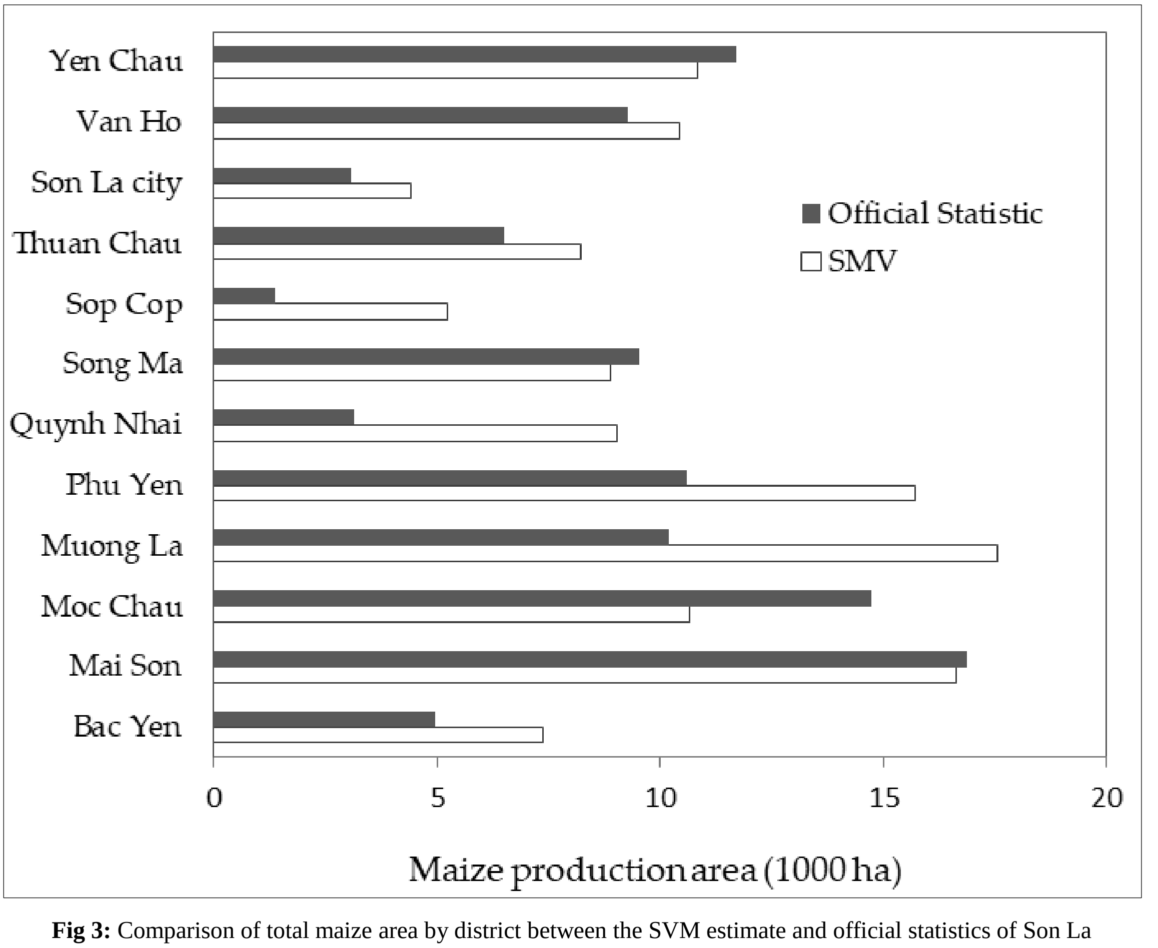
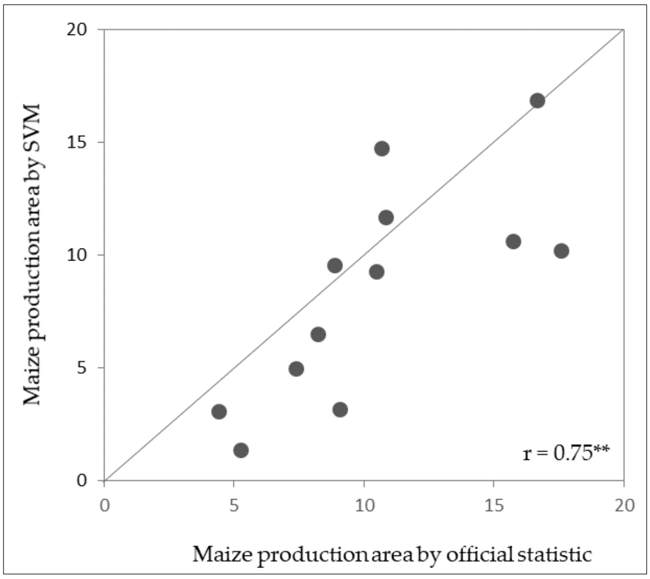


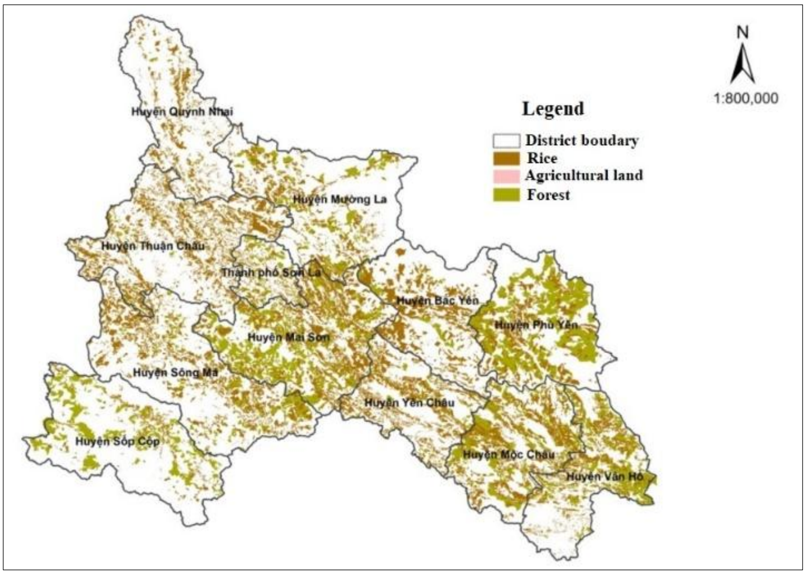
Fig 3: Comparison of total maize area by district between the SVM estimate and official statistics of Son La



** means significant at p<0.01

Fig 4: Correlation of maize area between SVM classification estimate and statistics of Son La province

The SG filter is an efficient method to reduce contamination in the MODIS-EVI time series caused by cloud contamination and atmospheric variability (Wang *et al*., 2011; Chakraborty and Das, 2012) [16, 6]. Therefore, it is widely used to map large-scale croplands, their cropping patterns, and crop types (Zhang *et al*., 2014; Chen *et al*., 2018) [20, 7]. Zhang *et al*. (2014) [20] also showed that different land cover types represent their own MODIS-EVI time series curves, which could be used to distinguish the satellite-derived maize distribution from other land cover types. In Vietnam, the SG algorithm has demonstrated great potential in reconstructing the EVI profiles of 7 vegetation types (maize, rice/other cereals, forest, industrial and fruit crops, grassland, and vacant/residential land) in Dak Lak – a province in Highland Center with a high accuracy of 79%. In our study, the SG filter was applied to reconstruct the EVI profile of maize and other vegetation types in Son La where cloud cover difficulty is a prominent issue in mapping the current situation of maize production. Chen *et al*. (2018) [7] pointed out that besides cloud shadow contamination, temporal interpolation, smoothing, spatial sampling, and assumptions for the cropping and mixed pixels may also affect the cropping pattern and crop type mapping results. By manually adding the missing EVI pixel values and smoothing the EVI curve based on the temporal characteristics of the greenness value of each plant, the SG can distinguish the maize growing season from other crops. This is important because extensive farming practices and complex growing systems in an often changing and interwoven landscape of Son La make it difficult for the system to identify which crops and where they are grown, especially for annual crops. That is the reason why the official land use map cannot provide detailed information about the annual crops that are grown locally other than rice (Figure 5). In fact, traditionally constructed maps only show annual crops including maize, and often fail to delineate abandoned areas.



Source: Official 2015

Fig 5: The latest updated agricultural land use statistical map of Son La province

In this study, although the SG filter reduced the contamination, the difference between the estimated maize area by SVM and official statistics was still around 22.6%. Chen *et al*. (2018) [7] claimed that although the 16-day MODIS removed the clouds and shadows, some omitted contaminated time points still exist in the rainy season. According to a field survey, maize in Son La is mostly grown in the summer/autumn season from late March to the end of July and some cases in the autumn/winter season from August to November. Therefore, heavy rain especially in Jun and July may impact estimation by satellite image. Moreover, the MOD13Q1 EVI has advantages in providing information on the management of crop growth and vegetation cover changes on a large scale, but the spatial resolution limited to 250 m is a major obstacle. In finding information about the area when the size of that field is less than the MOD13Q1 pixel size of 62500 m^2. That means that any maizefield with an area smaller than the pixel size will not appear on the map due to interference with the EVI signal/value of another more dominant vegetation cover. Furthermore, scattered maizefields will also not appear in the SVM classification process due to the linear nature of the SVM algorithm. Chen *et al*. (2018) [7] also found the same problem in mapping of single cropping system of soybean, maize, cotton cultivation, and mixed cultures with overestimation and bias of crop type assessment based on statistical data. In Son La province, maize is grown on small scales on steep hills or scattered between forest patches. It is possible that this distribution caused errors when estimating maize area by mixing pixels with forest or other annual crops. This can also be seen in districts with large afforestation areas such as Sop Cop, Phu Yen, Muong La, or Quynh Nhai, the errors between the two methods were larger than in other districts such as Song Ma, Mai Son, Yen Chau, or Van Ho, where maize grown more concentratedly in large scales.

The linear core SVM classifier is capable of mapping the maize crop model with a total accuracy of 81,6% but loses almost 18% of the GPS-confirmed fields for the other annual crop groups. The area difference in the satellite map may be due to the narrow margin of the superplanes separating maize and other crops. This problem can be solved in two ways: First, by selecting a better representative sample with the aid of a more representative GPS maizefield, based on the distribution over the landscape, and second, by comparing it with other non-linear core SVM classifiers.

4. Conclusion

The Support Vector Machine classifier shows that with suitable and representative training samples, it can map the distribution of maize cropping patterns in Son La with an accuracy of 81,6% compared to the ground information. The maize acreage estimated by the SVM classifier at the district level agrees well with the official data, with a correlation coefficient of r = 0.75. We suggest that further improvement of the maize cropping pattern map can be achieved when higher spatial resolution remote sensing data are available and better representative training samples for the whole region are considered.

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