Remote sensing and GIS application in assessing the adaptability of some key crops in Dak Nong province

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Abstract. Remote sensing (RS) and Geographic information system (GIS) is widely applied in the world and gradually affirms its role in Vietnam in managing agricultural and forest resources. This application is highly effective, providing information timely for managers to make decisions and build development strategies. In this study, RS and GIS were integrated to assess suitability for key crop species in Dak Nong province including coffee, rubber, cashew, and durian based on their suitability to site conditions such as soil (soil type, soil texture, soil thickness), topography (elevation, slope) and climate (temperature, precipitation). Using the restrictive method and overlapping map layers of natural factors, classified into adaptive levels according to FAO (1976). Results show that most land areas in Dak Nong province have different levels of potential suitability for key crop species ranging from non-adaptive to less-adaptive and moderately adaptive. However, most suitable areas for key crops are only at low (accounting for a large proportion) and the average adaptation level. The findings from the study are the scientific information for managers to make decisions regarding the structure of major crops in the province.

1. Introduction

In land resources planning and management, assessing soil adaptation is the key step that provides the basic information for land use planning and crops structure. The Food and Agriculture Organization of the United Nations - FAO (1985) [7] pointed out the need for the appropriate use of each type of soil for different crops in a rational way to continue sustainable cultivation, meet social need as well as conserve fragile ecosystems. One method of soil assessment that was widely used by experts is the land suitability assessment method developed by FAO (1976) [6]. This method assesses the suitability of land for a particular use by comparing potential uses with current uses, through land assessment we can know land resources have been used optimally or not, or how to adjust the land use purpose in the most optimal way. GIS was used by Ekanayake and Dayawansa (2003) [4] to identify potential areas for afforestation, the results showed that most of the land in the study area did not conform to the given criteria. Studies have also shown that multi-layer GIS analysis will make it easier to develop optimal use of land, increase
productivity while preserving environmental conditions as well as handling a large amount of accessible information about soils (Patil et al. (2001) [11], Dengiz et al. (2003) [3]).

Like other localities, the reality of agricultural land use in Dak Nong province is strongly influenced by the impact of prices, moreover, with fertile soil favorable for the development of many crops, especially industrial crops as well as fruit trees. Because of that, it leads to rampant farming without planning, or lack of planning that leads to waste of natural resources and human resources. Therefore, it is necessary to analyze the potential adaptability of crops as a basis to minimize the risks as well as the loss of resources, economy of the people and society. Moreover, in the context of climate change, the selection of crops as well as cultivated methods also needs to be proactive to adapt to climate changes that have a significant impact on production efficiency.

Information on adaptive soil units that need to be determined on a spatial and attribute basis is important in order to be able to determine its property and scope. This information needs to be determined by an aggregate way. For example, to grow a certain crop, it is indispensable for information on plant ecology such as soil requirements, temperature, water, altitude, etc.; In contrast, in areas with high slopes, far from surface water sources, frequent droughts, etc., the selection of agro-forestry options is very important. On a larger scale, aggregated information about natural and social conditions will help to make planning more accurate, thereby supporting planning as well as decision making and directional development strategy. This is the basis for the conversion or solutions to improve crop production efficiency. In addition, land use information is also an important component in understanding the interaction between human activities and the environment.

Geographic information system (GIS) is widely applied in the world and gradually asserts its role in Vietnam in term of managing agro-forestry resources. This application brings high efficiency, provides timely and objective information for managers to make decisions and build development strategies. However, through the review of the agricultural database system of the provinces in general, Dak Nong in particular still has many limitations, mainly due to the lack of digital data on the tree distribution map which were grown in different soil conditions. This causes many difficulties in management, strategic planning, as well as calling for investment. Therefore, this research has used GIS and Remote sensing (RS) as the effective tools to create land adaptation units for some key crops, which is important information as a basis for choosing or transforming crops in Dak Nong province.

The objective of this research were analyzing potential adaptation and reality land use of some key crops in Dak Nong province based on integrating multi factors analysis.

2. Study area and methods

2.1. Study area

The study was conducted in Dak Nong Province in the Central Highlands of Vietnam (Figure 1). It located in the geographical coordinates from 11°45’ to 12°50’ North latitude, 107°13’ to 108°10 East longitude. The average elevation is 700m above sea level. The mean temperature is 24 degrees Celsius. The climate conditions produce general characteristics of a subequatorial tropical monsoon climate. The province has characteristics of humid tropical highland climate and is affected by dry-hot southwest monsoons. There are two distinct annual seasons: the rainy season starts in April and ends in November, and the dry season starts in December and ends in March the following year. The average annual rainfall is 2,500mm, of which 90% occurs during the rainy season which supplies enough water for agriculture. However, it also causes erosion, landslide, flood which affect the human life and productive activities in the areas; In dry season average rainfall takes only 10% of the year. Because of that, some areas have severe drought especially in Cu Jut district, some communes in the East of Dak Mil and the North of Krong No district. The main wind direction in the rainy season is southwest, in the dry season is northeast, the average wind speed is 2.4 - 5.4 m/s. There are almost no storms so it does not affect fragile crops like coffee, rubber, and pepper.
The study area is 650,927 ha in which, agricultural land is 366,401ha takes a proportion of 56.29% total natural area. Almost the agricultural lands are perennial crops and forestry land; annual crops are rice, corn and beans (Dak Nong statistical yearbook-2019) [2].

2.2. Methods

Data collecting: All data such as Sentinel 1A and 2A images, digital elevation model (DEM), land use, soil, weather, and geographic map collected to build maps assessing potential land of key crops.

- Sentinel images, which resample of 10x10 m resolution acquired in 2020 and DEM achieved from Google Earth Engine (GEE) were used for creating slope, elevation, and crop maps
- Remote sensing and GIS used for creating the land use map in 2020
- Soil type, soil texture, and soil thickness were extracted from land map which derived by Sub National Institute of Agricultural Planning and Projection in Central Vietnam in 2005.
- Precipitation, temperature maps were produced based on weather data of Central Highland Hydro-Meteorological Centre in 2020. IDW tool in ArcGIS was used to interpolate rainfall and temperature maps.

Building key crops map: Sentinel-2A images were processed at level-1C including radiometric and geometric corrections. Ortho-rectification and spatial registration on a global reference system with sub-pixel accuracy (Sentinel-2 user handbook) [5]. Cloud cover was removed automatically in GEE; Sentinel-1A image was collected by GEE and processed at level-1 including Thermal noise removal, Radiometric calibration, speckle filtering using Enhanced Lee filter; It was also analysed image structure using Grey level co-occurrence matrix (GLCM) method to improve the classification. The pre-processed Sentinel-2A and Sentinel-1A images were combined to form a single image to serve as input data for image classification and identification of land cover/land use types (LULC). 5,158 sample points which were collected using Google Earth (GE), available data, field collected were used to discriminate LULC. In which, 60% of the sample were used for classification, the remaining was used for accuracy assessment. The two algorithms of Random Forest (RF) and Super vector machine (SVM) were used to classify the image. In this case, the validation shown that although the efficiency of the two methods is almost the same, the SVM took a long time (nearly 10 times comparing to RF), so RF was employed to classify the image into different LULC types. Using Object based image analysis (OBIA) method together with RF algorithm to determine LULC for the province. First, satellite images were segmented into objects using multiresolution segmentation method in eCognition software. Then, the image consisting of segmented objects is extracted in TIF file with the average values of the image channels and the normalized difference vegetation index (NDVI). Finally, the image containing segmented objects is classified using the RF based on the training dataset.
**Accuracy assessment**: The study employed sample points in the testing data based on the criteria of overall accuracy, producer accuracy and user accuracy to assess the classification accuracy. In addition, the Kappa coefficient also indicates the accuracy of the classification results compared to reality. The Kappa index values varies between 0 to 1 where, the closer it is to one, the closer the accuracy level of the map obtained from classification to reality (Abdi, 2005). The remaining 40% of the sample dataset employed to assess the accuracy of the classified image.

**Assessing potential adaptation of land use unit (LUU) for key crops based on multi-factors**: Overlaying factors map according adaptive level to form LUU. The key crops identified in this area are those that have a large area and/or contribute mainly to the household’s income. Accordingly, the key crops were selected in this area including coffee and pepper, rubber, and cashew. Restrictive method was used to assess the adaptability LUU for each key crops. This method used the least suitable factor as restrictive factor (FAO, 1993) [9]. According to FAO (1993), natural adaptation of crops divided into four levels including non-suitable (N), very high suitable (S1), moderate suitable (S2) and least suitable (S3). One LUU that is seen as very high suitable for a certain crop when all factors are very high suitable (S1) for that crop. In contrast, if a LUU has at least one factor that non suitable (N) for a crop, the LUU is not adaptable for that crop. If not in these two cases, the LUU is considered to be less suitable for a crop when there is at least one element of the least adaptive class (S3). Finally, the LUU is considered as moderately adapted when it does not fall into the above three cases.

**Determining the adaptability of key crop species based on multiple factors**: Crop plants growing depends on many environmental factors such as soil, water, temperature, slope etc. In addition, each crop requires certain condition of environmental factors. Using four levels of crops’ natural adaptation such as N, S1, S2, and S3 which have defined in the previous step to determine suitable areas for each crop. Although the crops depend on many elements during their growing, some main ecological requirements of crops such as soil type, soil texture, soil thickness, slope, elevation, temperature and rainfall were used under the current study due to available relevant data in this area. All multi-factors were divided into four levels as described above for the entire province.

Using Overlay Intersect function to build the map of potential adaptation for each crop. Areas of intersection between objects on factor maps will form new objects with all 7 attributes (soil type, soil thickness, soil texture, elevation, slope, maximum temperature, and average rainfall) of the factor maps.

Assessing the current status of the key crops in the province based on adaptation levels using land unit suitable to each crop with single factors, and integrated factors. The next step is to overlay the adaptive maps with the crop maps to determinate the state of the cultivated main crops (illustrated as Figure 2) as a foundation for proposing conversion. Figure 3 presents the diagram of research steps.

![Figure 2: Overlay adaptive factors map with current LULC map](image-url)
3. Results and discussion

3.1. Accuracy assessment

Ten of LULC were distinguished in the study using the Sentinel satellite images. They composed of natural forest (1), plantation forest (2), rubber (3), cashew (4), coffee and pepper (5), other crops (6) (e.g. fruit, cassava,…), annual crops (7), residential area (8), water surface (9), and other lands (10). Table 1 shows the results of overall accuracy (OA), Kappa index, Producer Accuracy (PA) and User Accuracy (UA). The OA of the classification was 75.57 % with a kappa of 0.70, indicating a strong agreement between the classification results and validation data. Most LULC obtained more than 60 % of accuracy, except for other crops, which had PA of about 48.38 %. It is found that the water surface was very distinguishable compared to other LULC classes due to its feature, so this class derived the most accurate result with PA = 100 % and UA =89.38 %. The following received from natural forests with PA=92.71% and UA=84.79%. The natural forests are easy to distinguish from other types because of their relatively high homogeneity and less fragmentation. Among the key crops coffee and pepper class presented the best accuracy with the values more than 70% both PA and UA; thought UA of rubber class was more than 80%, the UA obtained below 70%. In practice, the ages of industrial crops such as coffee, pepper, cashew, rubber vary widely. Although the same plant species, but their age varies from new plants (e.g. a few pairs of leaves) to mature trees (harvested, closed canopy). Moreover, the intercropping with 2-3 species of plants in the same garden plot is very common in the area. This makes it difficult to clearly distinguish these crops from other land covers, resulting in not really high in accuracy.

| LULC Category         | OA (%) | Kappa | PA (%) | UA (%) |
|-----------------------|--------|-------|--------|--------|
| Natural Forest        | 92.71  | 0.68  | 92.71  | 84.79  |
| Plantation Forest     | 92.71  | 0.68  | 92.71  | 84.79  |
| Rubber                | 79.24  | 0.65  | 89.38  | 76.54  |
| Cashew                | 89.38  | 0.68  | 89.38  | 76.54  |
| Coffee and Pepper     | 79.24  | 0.65  | 79.24  | 74.15  |
| Other Crops           | 48.38  | 0.56  | 48.38  | 40.32  |
| Annual Crops          | 75.57  | 0.70  | 75.57  | 70.46  |
| Residential Area      | 75.57  | 0.70  | 75.57  | 70.46  |
| Water Surface         | 100.00 | 1.00  | 100.00 | 89.38  |
| Other Lands           | 60.00  | 0.65  | 60.00  | 55.00  |

Table 1. Overall Accuracy (%), Kappa coefficient, Producer’s Accuracy (%), and User’s Accuracy (%) index for the classification image
| LULC          | 1   | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | UA% |
|--------------|-----|----|----|----|----|----|----|----|----|----|-----|
| 1            | 1857| 46 | 76 | 118| 53 | 22 | 18 | 0  | 0  | 0  | 84.79|
| 2            | 25  | 251| 14 | 8  | 4  | 0  | 13 | 5  | 0  | 0  | 78.44|
| 3            | 30  | 6  | 451| 7  | 23 | 0  | 0  | 0  | 0  | 0  | 87.23|
| 4            | 59  | 6  | 32 | 147| 54 | 0  | 0  | 0  | 21 | 66.24|
| 5            | 24  | 5  | 59 | 175| 1369| 174| 61 | 1  | 32 | 72.05|
| 6            | 8   | 15 | 9  | 22 | 84 | 128| 44 | 8  | 0  | 23 | 57.14|
| 7            | 0   | 0  | 4  | 7  | 12 | 12 | 193| 34 | 0  | 14 | 69.93|
| 8            | 0   | 0  | 7  | 0  | 1  | 8  | 24 | 121| 0  | 0  | 75.16|
| 9            | 0   | 0  | 0  | 5  | 5  | 0  | 7  | 143| 0  | 0  | 89.38|
| 10           | 0   | 8  | 0  | 3  | 38 | 33 | 0  | 15 | 0  | 175| 64.34|

PA%  92.71  74.48  69.17  64.47  78.86  48.38  53.61  65.76  100.00  66.04  Kapa= 0.70

OA= 75.57%

1: Natural forest, 2: plantation, 3: rubber, 4: cashew 5: coffee and pepper, 6: other crops, 7: annual crops, 8: residential area, 9: water surface, 10: other lands

### 3.2. Tabular of LULC

In order to harmonize with LULC data existing in the Dak Nong province, the LULC which detected based on satellite image were also adjusted after confirming with localities through seminars and comparing with the 2019 and 2020 statistical yearbooks. The final results are filtered, adjusted and vectored. Among the LULC classes, the forest area covers as the largest portion of the total area (35.09%), key crops such as coffee area cover 25.20%, rubber is of 3.65%, and cashew is of 2.47%. The illustration is shown in Figure 3.

*Figure 4. Percentage of land use/ key crops*

Forestry land has the largest area, with an area of 228.43 thousand hectares, accounting for 35.09%. Among other land use types (including water surface), coffee and pepper class has the largest area of 164.01 thousand ha, accounting for 25.20%, widely distributed in all districts of the province, of which Dak Song and Dak Mil has the largest area. Followed by other crops and annual crops accounted for 13.46% and 12.24%, respectively. Cashew has been planted about 16.09 thousand hectares, accounting for 2.47%, mainly in Cu Jut, Tuy Duc and Krong No districts. Rubber area is mainly in Cu Jut, Tuy Duc, Dak R'lap and Krong No districts with about 23.74 thousand ha.

### 3.3. Adaptive ability of key crops

#### Soil map

The map of soil types was collected from Sub National Institute of Agricultural Planning and Projection in Central Vietnam. There are eleven soil types within the area including newly modified soil, eroded soil, red soil, grey soil, alluvial soil, dark brown soil, compacted clay, black soil, cracked soil, grey soil, brown soil (Table 2).
Table 2. Soil type statistics

| No. | Sign | Soil type              | Area   | (%)  |
|-----|------|------------------------|--------|------|
| 1   | CM   | Newly modified soil    | 11,125 | 1.71 |
| 2   | E    | Eroded soil           | 9,389  | 1.45 |
| 3   | Fd   | Red soil              | 391,837 | 60.32 |
| 4   | GL   | Gley soil             | 5,303  | 0.82 |
| 5   | P    | Alluvial soil         | 2,669  | 0.41 |
| 6   | PH   | Dark brown soil       | 27,387 | 4.22 |
| 7   | PL   | Compacted clay soil   | 338    | 0.05 |
| 8   | R    | Black soil            | 1,292  | 0.20 |
| 9   | VR   | Cracked soil          | 2,681  | 0.41 |
| 10  | X    | Grey soil             | 185,809 | 28.61 |
| 11  | XK   | Brown soil            | 11,730 | 1.81 |

Soil thickness

Soil thickness was classified into 5 levels including: <30cm, 30-50cm; 50-70cm; 70-100cm; >100cm (FAO, 1993b) [8]. Almost soil thickness in the area was above 100cm with the area about 449,000ha (68.86%). This characteristic is suitable for industrial crops such as coffee, pepper, cashew, rubber, etc. The second level was < 30cm that cover about 711,124.3ha (10.91% of land in total).

Soil texture

Soil texture was classified into four levels including loam, sandy, silty loam and clay. Soil with loam and clay texture take a large proportion of the area which are suitable for industrial crop such as coffee and rubber plantation. Of which, loam soil is of 67.35% and clay soil with 25.61%.

Slope

Slope is varying from zero to 60.32° and divided into 6 levels: <3°, 3-8°, 8-15°, 15-20°, 20-25°, >25°. Slope level 3-8° and level 8-15° occupy the largest area with the proportion of 32.85% and 32.59% respectively.

Annual rainfall

Annual rainfall in Dak Nong province is from 1,400 – 3,000mm. Rainfall hierarchy map was built with 4 levels: 1,482 – 1,700mm, 1,700 – 2,100mm, 2,100 – 2,500mm, >2,500mm. Accordingly, the rainfall level of 2,100 – 2,500mm has the largest area with 32.46%, the other take equivalent proportion from 21 – 24% (Table 3).

Table 3. Area of rainfall levels

| No. | Rainfall level (mm) | Area (ha) | (%)  |
|-----|---------------------|-----------|------|
| 1   | 1,482 – 1,700       | 161,416.25 | 24.80 |
| 2   | 1,700 – 2,100       | 138,760.25 | 21.32 |
| 3   | 2,100 – 2,500       | 211,308.25 | 32.46 |
| 4   | >2,500              | 139,442.25 | 21.42 |
|     | Total               | 650,927.00 | 100.00 |

Temperature

The annual average maximum temperature goes from 25 – 32°C in this area. The temperature was classified into three levels: 25 – 27°C, 27 – 30°C, >30°C for the entire area. In which, temperature level 27 – 30°C has the largest proportion with 61.87% and the second is over 30°C with 24.25%. This high temperature is very suitable for coffee, rubber and cashew.

The overlaying multi-factor maps and current key crop maps was conducted to identify adaptability levels of each. Simultaneously, adaptation analysis was also carried out on the entire area of the province with some popular crops such as citrus, pomelo, durian, avocado, etc...to serve as a basis for conversion of non-adapted areas of the key crops or crop planning more appropriate. The result The LULC map was overlaid on the multi-factor maps to determine the current state. The results indicated that out of 164,000 ha of coffee, about 92.5 thousand ha have been grown in less-adapted to moderate-adapted
areas, about 57% respectively, and un-adapted area is about 70.01 thousand ha, equivalent to 43% of the province's coffee area. Comparison of adaptability to other species as mentioned above, about 32.55 thousand ha of these can be converted to other crops such as rubber, cashew, durian, oranges, tangerines and pomelos.

Similarity, some areas of 11.07 thousand ha of un-adapted cashew cultivation can be converted to other crops such as rubber, coffee, durian, oranges, tangerines and pomelos; with 12.06 thousand ha of rubber cultivation under the non-adapted category, only about 34.51% of the area can be converted to other crops such as cashew, coffee and fruit trees.

In all three cases of crops, there are many non-adapted areas for which suitable crops have not been identified. For these areas, it needs studies and trials of new plants to make recommendations, or afforestation with native trees, afforestation of raw materials, multi-purpose forestry trees in the form of pure planting, or agroforestry to increase the cover to contribute to climate change mitigation.

For the natural area of the province, adaptability analysis for the key crops was indicated in Table 4. However the planning should be considered to specific areas which exclude other LULCs such forestry land, residential area, etc.

| Adapted levels  | Coffee, pepper | Rubber | Cashew |
|-----------------|---------------|-------|--------|
| Area (ha)       | (%)           | Area (ha) | (%) | Area (ha) | (%) |
| Non suitable    | 356,125.00    | 57.06  | 424,059.00 | 65.84 | 579,170.8 | 89.93 |
| Least suitable  | 194,728.00    | 31.20  | 207,597.00 | 32.23 | 64,833.35 | 10.07 |
| Moderate        | 73,287.60     | 11.74  | 12,371.20 | 1.92  | 8.78       | 0.0014 |

The result also shows that suitable lands for some key crops in Dak Nong province are distributing in different places and the most adapted lands are concentrating in the central and the south of the province (Figure 4). It indicates that the average proportion of suitable lands for growing these species is quite low, especially cashew trees comparing to other crops.

Figure 5. Potential adaptation soil for key crops in Dak Nong province: a) coffee and pepper, b) rubber, and c) cashew

4. Conclusions
Integration of remote sensing and GIS application is useful to analyse the adaptability of crops. The analysis provide basis for determining the current cultivation and recommending to convert the areas which are under crop requirements. In practice, the cultivation of a certain crop on a less or unsuitable area is often compensated by highly intensive farming, using a lot of chemical fertilizers, which results in residues in the product and contaminates the environment. In addition, the production efficiency may be low because of the high investment. Therefore, determining the area suitable for crops contributes more effectively in farming not only for economic, society, and for environment as well in some ways.

Although the OA is quite high in the present study, the PA and/or UA of the main crop is not really high, so additional approaches are needed to improve the classification accuracy. In addition, some other factors such as humidity, altitude, water source, etc. should also be considered in the analysis of LUU adaptation for crops.
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