Agricultural Land Use Planning with GIS-based Land Suitability for Crop Combination

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ABSTRACT

Land suitability maps are generally established based on individual crop types, which provides inadequate information for land use planning. In this study, land evaluation is accomplished with the objective of delineating units of land as to their suitability for combining economic crops with legal conservation areas. The study area is the Chi watershed, which covers an extensive portion in Northeast Thailand with an area of about 49,500 sq km. The major economic crops in the area are rice, sugar-cane, cassava and rubber tree. The suitability assessment for each crop was conducted following the method described in FAO guidelines. The land suitability for each crop was established using an overlay process of defined land quality layers. Land suitability maps, with their associated class attributes were prepared for rice, sugar-cane, cassava and rubber tree. In addition, the conservation areas in the watershed were also digitally encoded in GIS database. Simultaneously, overlay process was then performed of the suitability layers and conservation areas with selection criteria of identifying conservation area, highly and moderately suitable classes. The resultant map obtained is a result of combination of defined suitability class of combining crops and the conservation areas. The planning alternative that best matches land uses to the highly and moderately suitable land areas was suggested with respect to the conservation area

KEY WORDS: Land Evaluation, GIS, Land Use Planning

1. BACKGROUND

Agricultural land use planning requires spatial information on the land suitability for avariety of economic crops within agricultural areas. Currently, the FAO guidelines for land evaluation are widely accepted (FAO, 1983). The FAO land evaluation system is based on an integration of various land qualities as they relate to individual crop requirements. A similar system, developed by Sys et al. (1991), provides the crop requirements based on the experimental studies and results over land in the tropics. To formulate effective land use planning, the evaluation has to provide alternative plans with more or less marketing risk. To lower marketing risk, the combination of various economic crops within the area should be considered and evaluated. Rice, sugar-cane, cassava and rubber trees are important export crops and products from Thailand. Their combined crop area is extensive and covers over 70% of the total cultivated land in Northeast Thailand. In Thailand, land classifications have been conducted over the past three decades. The classification system includes land capability classes for field crops and land suitability classes for rice (Land Development Department (LDD), 1996). To date, the land suitability maps are defined as the inherent capacity of a soil to grow crops. The overall mapping process still considers the inherent capacity of soils in defining the suitability of the land unit. Recently, these land suitability maps were digitally encoded in a geographic information systems (GIS) database. Furthermore, a number of pilot projects have been undertaken to test the land evaluation method using GIS. There still remains the need to establish an integration method for the relevant land qualities in the modeling of land suitability.

With the advent of new technologies, the integration of land qualities in land evaluation are effectively accomplished using satellite data and GIS functionalities (Yamamoto et al., 2003, Thavone , 1999, Duc, 1999, Mongkolsawat et al., 1999 and Mongkolsawat et al. 1997). The studies are based on fairly similar concepts, but use different models for the land quality integration. The land qualities defined may vary from region to region depending upon the information available and techniques used. In the study area analyzed here, the land use types include rice, sugar-cane, and cassava, as well as recent and rapidly expanding plantings of rubber trees. The mis-management of land is common to this area with unsuitable land, forest reserves, and sloping lands encroached upon for agriculture. This study provides a GIS-based approach on the suitability of land for individual crop types, and the combination of selected economic crops. Based on which the agricultural land use planning can be formulated with higher reliable and informative and eventually to lessen the marketing risk. The objective of this study is to develop a GIS-based method that analyzes and considers land suitability for integrating multiple economic crops at the watershed level, in support agricultural land use planning.

2. STUDY AREA

The study area encompasses an extensive portion of the central part of northeastern Thailand. It includes the Chi Watershed, which is being used as a test area for agricultural land use planning in the region (Fig.1). The Chi watershed is drained to the east by the Mun river and eventually by the Mekong river at the Thai-Lao, PDR border. Physiographically, the Chi Watershed is formed by the strong topography in the upstream portion and flat to gently undulating landscapes in the central and downstream portions of the river. The land cover consists of dipterocarp and evergreen forests in the upland mountain zone, field crops on the well drained soils of the gently undulating areas, and paddy rice on the flat and low lying areas. Isolated patches of remnant forest are commonly found throughout the Chi Watershed. Geologically the area is underlain by a thick sequence of Mesozoic sediment, the Korat Group ranging in age from upper Triassic to Tertiary. The extensive alluvial plain is underlain by the Maha Sarakham Formation (a formation of the Korat Group), which was deeply weathered in the Tertiary period and contains considerable quantities of evaporites interbedded with sandstones siltstones and sandy shales. The occurrence of this formation coincides with the distribution of salt affected soils. The soils on the undulating landscapes are mainly derived from alluvium of sandstone origin. The mean annual rainfall ranges from 1000-1500 mm. and increases from the west to the east portions of the region.

3. METHODOLOGY

3.1 Land suitability for crops

Selected crops/plants (rice, sugar-cane, cassava and rubber trees) were evaluated based on the FAO land evaluation system (FAO, 1983). For each crop, different land units resulting from the spatially combined overlay of defined land qualities were digitally established using GIS. The crop requirements in terms of the land qualities to be used in the evaluation process were previously reviewed (Sys et al., 1993; LDD, 1996; FAO, 1983; Mongkolsawat et al., 1999; Mongkolsawat, 1997; Paiboonsak et al., 2004a, 2004b). In the Chi Watershed, some of the FAO defined land qualities that yielded negligible difference within the region were excluded from the evaluation. Furthermore, various experimental field reports and regional experiences were also reviewed to help define the land qualities.

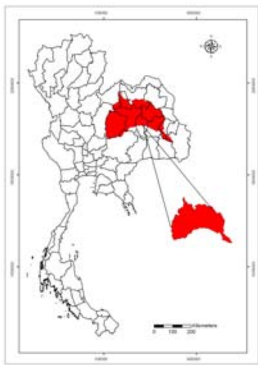

Fig.1 Study area

In the Chi Watershed, the qualities used in the evaluation were selected with reference to the land uses considered and the nature of the land units. The land qualities used in this evaluation included water availability (W), Nutrient Availability Index (NAI),Water retention (I), Rooting Conditions(R), Oxygen availability(O), Salt hazard (Sa), Flood hazard (F), Soil erosion (E) and Terrain (T). Each was treated as a thematic layer in the GIS database. Determinations of the factor rating values for individual land quality ranging from 1.0, 0.8, 0.4 and 0.1 for highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and unsuitable (N). The overall suitability evaluation for the crops in the Chi watershed is based on the multiplication equation FAO (1983):

Overall suitability = W x NAI x I x R x O x Sa x F x E xT …………………. (1)

with the following definitions,

a) Water availability (W): Rainfall data of 30 years (1975-2005) recorded by the Meteorological Department were used for the establishment of the 'W' layer. Spatially interpolated, mean annual rainfall for the entire Northeast region of Thailand was conducted with Kriging of the station data to yield a 'W' spatial map. The spatial 'W' layer was then divided to 4 suitability classes as defined by Mongkolsawat et al. (2009a), Charuppat and Mongkolsawat (2003), Putklang et al. (2010) and Mongkolsawat and Putklang (2010) for the crops to be evaluated.

b) Nutrient Availability Index (NAI): The NAI, is based on the method developed by Radcliffe et al. (1982) and is given by NAI= N x P x K x pH. The soil map provides information of N, P, K and pH, those of which were used in the overlay process to create the spatial layer of NAI. The values of the rating factor of the NAI component were given by Mongkolsawat et al. (2009a), Mongkolsawat et al.(2009b), Putklang et al. (2010) and Mongkolsawat and Putklang (2010).

c) Water retention (I): Water retention was compiled from soil texture on which the factor rating values for crops were based. The values assigned to the crops are referred to a number of studies (Mongkolsawat et al., 2009a, Mongkolsawat et al., 2009b , Putklang et al., 2010 and Mongkolsawat and Putklang, 2010) by which the 'I' layer was established.

d) Rooting Conditions(R): Rooting condition is a major land quality that plays important role in the land suitability evaluation. Soil depth is a diagnostic factor for the crops (Sys et al., 1993). Soil map developed by LDD (1991) provides the soil depth by which the factor rating values for the crops were assigned (Mongkolsawat et al., 2009a, Thavone, 1999, Putklang et al., 2010 and Mongkolsawat and Putklang, 2010).

e) Oxygen availability (O): Soil drainage as defined by USDA (1951), available from soil map (LDD, 1991) was used for the creation of the 'O' layer. The factor rating values were given by Mongkolsawat et al. (2009a), Mongkolsawat et al. (2009b), Putklang et al. (2010) and Mongkolsawat and Putklang (2010).

f) Salt hazard (Sa): Soil salinity is an important edaphic constraint for the crops and originates from the Maha Sarakham geoglogic formation which underlies the areas. An available soil salinity potential map (Mongkolsawat and Paiboonsak, 2006) was used to assign the factor rating for the evaluation.

g) Flood hazard (F): Flood hazard layer was performed using the recurrent flood area developed with multi-temporal Radarsat data for the periods of 2001,2002,2003,2004 and 2007. An available map layer of the recurrent flood area provided by Regional centre for Geo-Informatics and Space Technology, Northeast Thailand (2009) was used and assigned the factor rating values according to number of the recurrent flooded years.

h) Soil erosion (E): Soil erosion layer developed using universal soil loss equation prepared by Mongkolsawat et al. (2006) was used and assigned the factor rating values according to the soil erosion risk.

i) Terrain (T): The terrain layer is a matrix of slope gradient and landform. The map of the slope and landform combination was digitally established and the values assigned were given in the study conducted by (Mongkolsawat et al, 2009a, Mongkolsawat et al., 2009b, Putklang et al, 2010 and Mongkolsawat and Putklang, 2010) for rice, sugar-cane, cassava and rubber tree, respectively.

Each of the defined land qualities with their associated attribute was digitally encoded in GIS database to create the nine thematic layers. The diagnostic factors of each layer were assigned with factor rating values (S1=1.0 for highly suitable, S2 = 0.8 for moderately suitable, S3 = 0.4 for marginally suitable and N = 0.1 for unsuitable).

The evaluation model for each crop was given using the values of the factor rating as equation (1)

These layers were integrated by spatially overlaying each with the suitability model of the defined nine layers, which yielded 4 classes according to the results shown in table 1.

The reliability or accuracy of the suitability map for each crop was assessed, based on the suitability maps conducted by LDD (2005) for rubber tree and ground truth surveys for rice, sugar-cane and cassava. The number of the ground truth locations surveyed for rice, sugar-cane and cassava accounted for 66, 23 and 18 locational samples respectively .

Table 1 Overall suitability evaluation for rice, sugar-cane, cassava and rubber tree

Suitability Class	Rice	Sugarcane	Cassava	Rubber tree
S1	0.554-1.000	0.584-1.000	0.584-1.000	0.584-1.000
S2	0.054-0.554	0.085-0.584	0.085-0.584	0.085-0.584
S3	0.001-0.054	0.003-0.085	0.003-0.085	0.003-0.085
N	<0.001	<0.003	<0.003	<0.003

In each of locational samples, the crop performance and its yields were intensively identified, including famer’s interview. A number of approximations and corrections of the land units were subsequently made. This iteration process was performed to eventually obtain a satisfactory result. We applied the kappa statistic to assess the agreement between field-base and GIS based classification. The schematic chart of the methodology process is illustrated in figure 2.

3.2 Land suitability for crop combinations

In the evaluation of crop combinations, the suitability for each of crop of interest is obtained and inserted in the GIS model. An overlay process was further performed on these suitability layers with model criteria of only the highly and moderately suitable classes selected for identifying the suitability for the crop combination.

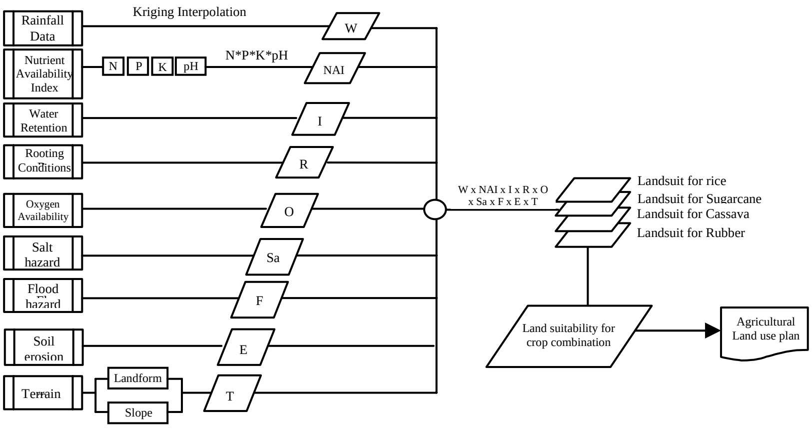

Fig 2. Schematic chart of the methodology process

3.3 Agricultural land use planning

Consideration of land in terms of suitability, management and conservation is needed for land use planning. In this procedure, the suitability of crop combination, conservation areas and community areas were integrated, providing the land units for land use planning. The integration was digitally performed by the overlay process with selection criteria defined for the planning with the suitability, conservation areas and community uses.

4. RESULTS AND DISCUSSIONS

4.1 The Suitability maps

The suitability map resulting from the spatial overlay of the land qualities for rice, sugar-cane, cassava and rubber tree are shown in Fig. 3 The suitability area in addition to the spatial information of the crops is shown in Table 2. The study provides the overall insight into each land quality for crops and the suitability resulting from the integrations of the land qualities spatially and quantitatively. It is evident from the study that land suitability for cassava covers over 38% of the area for highly and moderately suitable land.

The high suitability land for rice, sugar-cane, cassava and rubber tree cover areas of about 7.54, 8.81, 19.29 and 3.60% respectively (table 2). The conservation areas cover extensively in the dissected erosion surface and mountainous area where the land slope is evident. For the conservation requirements, the legal forest reserves are not covered by this assessment. The information obtained were further analyzed in the second stage to prepare the land unit for the crop combination.

Cassava and sugar-cane are the combination crops that normally occupy the upper terraces of well drained soils. With this information, the alternatives for agricultural land use are dynamic and varied according to the cost benefit analysis of the combination normally the low inputs of cropping factors and high return with the sustainability of land are recommended. To make any decision, it is necessary to develop alternatives for the areas that require methods of selection.

Table 2 The suitability area for rice, sugar-cane, cassava and rubber tree, Chi watershed, Northeast of Thailand

class	**%**			
	Rice	Sugar-cane	Cassava	Rubber tree
Highly suitable	7.54	8.81	19.29	3.60
Moderately suitable	10.83	26.48	19.99	19.52
Marginally suitable	31.17	9.64	6.71	21.46
Unsuitable	44.96	49.56	48.51	49.91
Total area of the Chi = 49,477 sq.km.				

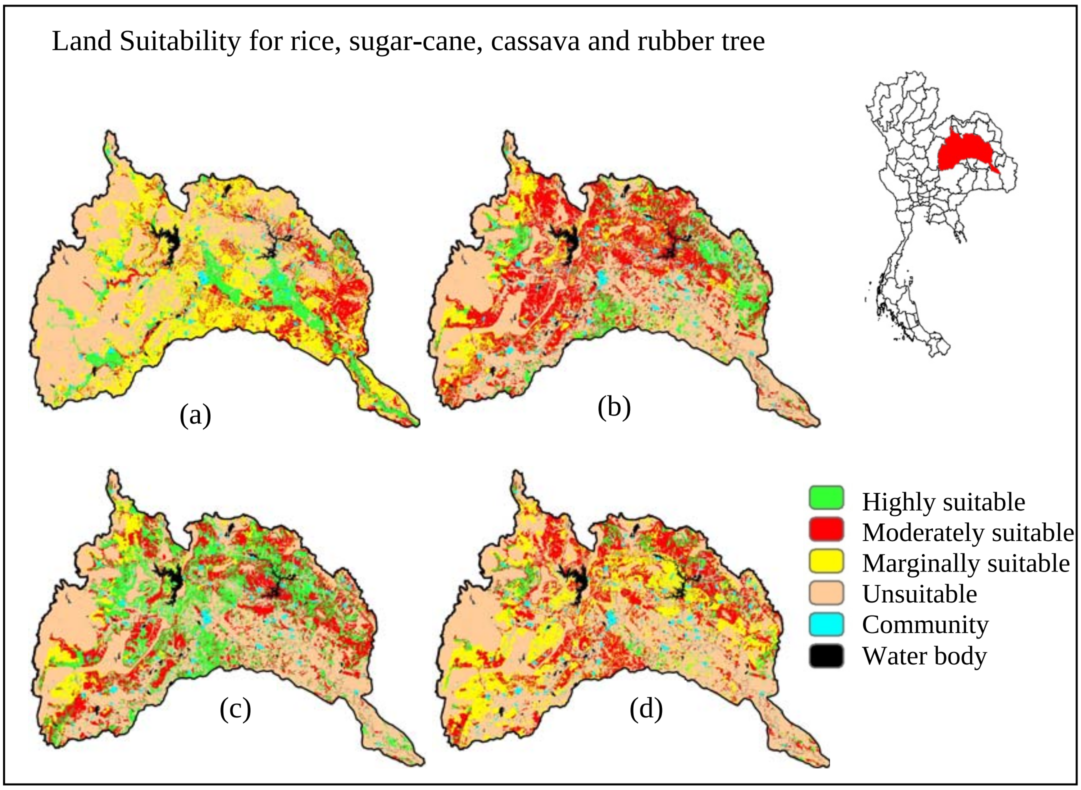

Fig3. Suitability map for rice (a), sugar-cane (b), cassava(c) and rubber tree (d)

4.2 Reliability of the suitability maps

The mismatches between the obtained map and field –based identification were 14, 30 and 33% for rice, sugar-cane and cassava respectively. The mismatches are likely due to intensive land management and high level inputs made by individual farmers .Of the 60 locational samples the agreement between the LDD maps and the established maps for the rubber tree was 48 locational samples for the combination of high and moderate classes.

4.3 Agricultural land use plan

The agricultural land use plan, based on the combination of crops, is shown in Fig. 4. The areas occupied by each unit are illustrated in Table 3.

This study provides information about the areas suitable for crops, not only individual crop types but also crop combinations. This provides opportunities for analyzing alternatives in agricultural land uses in order to lower marketing risks. Land suitable for rice was found extensively in the floodplains of the watershed. The legal reserve areas are restricted to the mountainous areas with steep slopes that are normally covered with dipterocarp and evergreen forests. The land use plan as identified in this study can be applied at the large watershed scale. At this scale we need a broad planning strategy, policies, priorities and operational planning to effectively implement a land use plan.

The integration of development needs and conservation is then needed. For these goals we still need the economical and social analysis, as well as public and executive-level discussions and the plan formulations to fulfill the planning. However, the spatial information provided in GIS offers the decision maker with reasonable suitability maps.

It should be observed that variations seen in the results of this study are apparently due to the values of each land quality unit assigned, particularly the soil and water availability classes. This will require further empirical research to improve the derivation of these values.

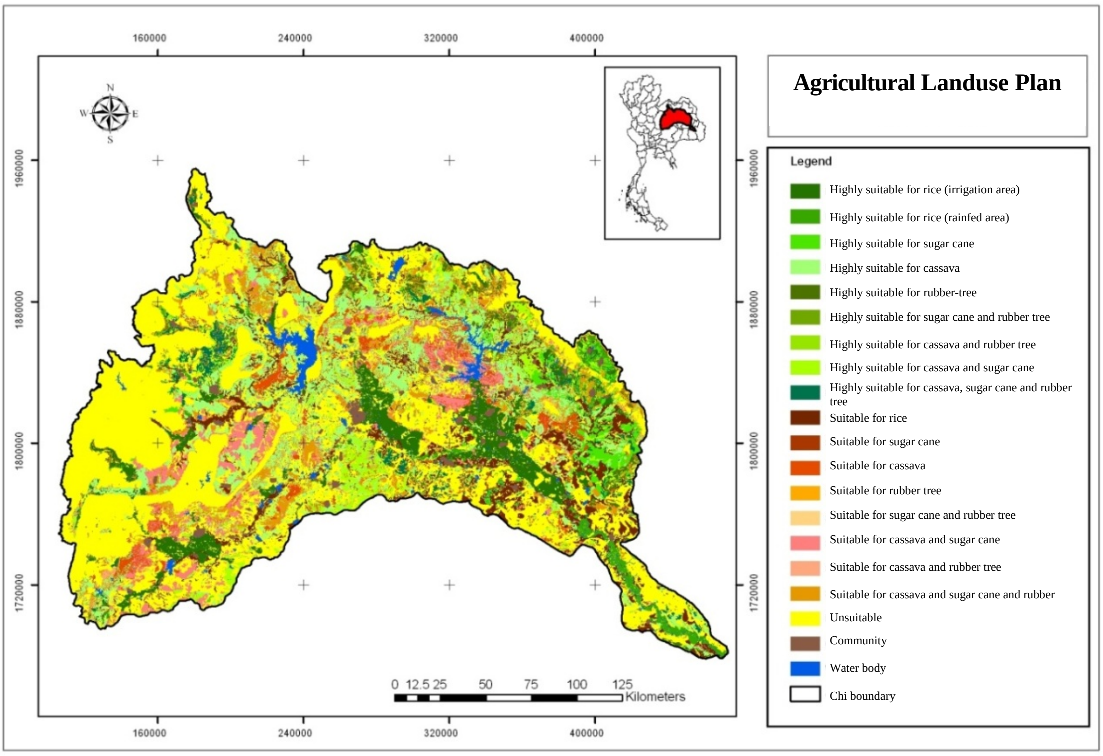

Fig4. Agricultural Landuse Plan

Table 3 Agricultural land use, The Chi watershed, Northeast Thailand.

Suitability	Area Sq. Km.	%
Highly suitable for rice (irrigation area)	2721.60	5.64
Highly suitable for rice (rainfed area)	872.41	1.81
Highly suitable for sugar cane	1052.49	2.18
Highly suitable for cassava	6009.44	12.45
Highly suitable for rubber-tree	780.76	1.62
Highly suitable for sugar cane and rubber tree	37.49	0.08
Highly suitable for cassava and rubber tree	4.21	0.01
Highly suitable for cassava and sugar cane	2139.42	4.43
Highly suitable for cassava, sugar cane and rubber tree	854.42	1.77
Total of highly suitable area	**14472.24**	**29.99**
Suitable for rice	3215.04	6.66
Suitable for sugar cane	40.26	0.08
Suitable for cassava	1681.12	3.48
Suitable for rubber tree	87.10	0.18
Suitable for sugar cane and rubber tree	7.36	0.02
Suitable for cassava and sugar cane	2655.07	5.50
Suitable for cassava and rubber tree	207.01	0.43
Suitable for cassava, sugar cane and rubber tree	2921.13	6.05
Total of suitable area	**10814.09**	**22.4**
Total of highly suitable and suitable area	**25286.33**	**52.39**
Unsuitable	20327.54	42.11
Community	1466.12	3.04
Water body	1189.18	2.46
Total of non-agriculture	2655.30	5.50
Total	**49,477.00**	**100.00**

5. CONCLUSIONS

In conclusion, the GIS-based land evaluation approach can provide thematic layers that enable the formulation of dynamic scenarios for integrating information. The integration process with geographic references is widely accepted for implementing spatial decision support systems. In terms of land management, the watershed is the area best suited for natural resource management and allocation of land uses for land sustainable development. The maps and their associated statistic provided the areas best suited to crop combination. We can formulate the plan by selecting crops with high economic return for the land unit of particular year. With GIS-based land evaluation, it is also possible to revise land use plans, as needed, in the future. It is suggested that particular land unit should be further analysed with empirical research.

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