Economic land evaluation for agricultural resource management in Northern Thailand

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1. Introduction

The need for an improved approach to using land resources for agricultural production in Thailand has been widely recognized. Such an approach should assist in the identification of land use options that are manageable within the context of the farmer’s resource base and that can improve the well-being of rural communities (Waithaka et al., 2006). Land evaluation can be used to provide land use options, incorporating both the dynamics and competitive nature of agricultural production systems. Land evaluation is a process which examines present and changing land performance, considering physical and economic factors (FAO, 1976).

Despite over 30-years of land evaluation analyses, the progress in method development has been disappointing. Johnson and Cramb (1996) state that the failure to predict crop yield and the inability to reflect a changing technology and economic situation are the weaknesses in the existing land evaluation techniques. Moreover, the systems do not provide information on the production and price risk which are critical to the survival of farmers. To predict crop yields, crop models are utilized. In Thailand, for example, rice models were used by Jintrawet (1995), sugar cane models by Promrit and Jintrawet (2001) and peanut models by Banterng et al. (2004). A limitation of existing crop models is their lack of spatial representation, due to their high demand for data and to their low predictive capacity at a larger scale (Williams and Probert, 1984). Such limitations have been somewhat addressed in later models e.g. CATCHCROP models in Perez et al. (2002) where the number of parameters have been much reduced. However, there are still more crop types for which models are not available e.g. longan, lychee, mango and tangerine.

In order to predict crop yield with fewer parameter requirements, the relationships between soil properties, climate and crop yields have been widely studied. Soil properties such as soil depth and moisture holding capacity are examined directly or indirectly as important factors for determining crop yields (De La Rosa et al., 1981; Olson and Olson, 1986). A study by Mandal et al. (2005) found correlations between cotton yields with agro-environment factors (soil physiographic conditions, growing periods, crop evapotranspiration and rainfall). The study used the FAO soil quality index (FAO, 1976) to derive yields. So, there have been attempts to use physical land suitability indices for estimating crop yields.

Land mapping units described in this paper are areas integrating physical, ecological, and socioeconomic data. As most land units are not suitable for all land use types, land evaluation classifies suitability into classes according to physical characteristics (Rossiter, 1995). This process entails integrating different types of information; however, uncertainties are not easily integrated in a systematic...
way (Ferraro et al., 2003). Previously, fuzzy set techniques have been used to standardize land attributes prior to applying specific decision rules for evaluating land suitability (e.g. Baja et al., 2002b; Groenemans et al., 1997; Nisar Ahamed et al., 2000; Sicat et al., 2005). Fuzzy set methods allow decisions on land suitability to be based upon imprecise information. Fuzzy set theory is a generalization of Boolean algebra to model attributes with zones of gradual transition, rather than sharp boundaries. This offers a useful way of representing uncertainty in land evaluation (Burrough, 1989).

A fuzzy set is characterized by its membership function. The grade of membership of an object can range from 0 to 1.0. The value of 1.0 denotes full membership and the closer the value is to 0 the weaker is the object’s membership in the fuzzy set (Zadeh, 1999). With regard to land suitability, Van Ranst et al. (1996) determined the quantitative impact of land qualities on rubber production grown on a wide range of soils under different climate conditions in Thailand. They used fuzzy set theory to evaluate land qualities in a land suitability index which was used to predict relative yield by means of multiple regression on various land qualities. Braimoh et al. (2004) applied fuzzy set and interpolation techniques for land suitability evaluation for maize. Land suitability indices were computed at points and then spatially interpolated. It was found that the interpolated GIS land suitability was closely related to maize yield at the village level.

The fuzzy land evaluation approach provides a flexible process for combining information on land qualities into a final suitability index, where information provided is continuous. A set of land characteristics were selected by the Land Development Department in Thailand (Tansiri and Saifak, 1999) based on three criteria: an effect on the considered crop or land utilization type, an occurrence of critical values in the considered area, and information obtainability.

Once physical suitability has been assessed, economic land evaluation is implemented to provide predictions of economic value of a given land-use system for each land unit. Information derived from economic land evaluation is directly relevant to land-use decisions, which are made on the basis of economic value (Rossetter, 1995). Challenges nevertheless exist for economic land evaluation as economic variables such as crop price or production cost change frequently, especially through time and space. Additionally, different decision makers (e.g. farmers, policy makers) have different utilities (economic satisfaction) with respect to levels of returns for each land use.

The land evaluation process has many stages, and is complicated by the different needs of different users. To be effective and relevant, integrated evaluation approaches involve the consideration of multiple issues, methods and stakeholders to assess trade-offs in a transparent and systematic way (e.g. Jakeman and Letcher, 2003; Letcher et al., 2006a,b). At the regional scale, the task of integrated land evaluation can be facilitated through use of a geographic information system (GIS) to effectively build and store land mapping units and their attributes. There are many decision support systems that have been developed for land-related evaluation. van Walsum et al. (2008) developed a bioeconomic model for spatial planning of integrated land and water management and demonstrate the potential of the model for revealing and quantifying conflicts and interaction between regional objectives. ASSESS (Hill et al., 2005) has been used extensively in a policy environment. It uses the Analytic Hierarchy Process, Multi-Criteria Decision Analysis and GIS processing to assist with correlation of input data layers, subjective weightings, and mixing of qualitative and quantitative data.

A customized GIS interface is an effective way for users to interact in these processes (Densham, 1991). A good interface enables users to interact and feed inputs in easily understandable ways (Acock et al., 1999). For example, the IMGLP model (Nidumolu et al., 2007) is a useful communication support tool that considers objectives of multiple stakeholders and identifies possible bottlenecks in communication among stakeholders. Other examples include the Automated Land Evaluation System (ALES) (Rossetter and Wambeke, 1997), FUZZYLAND (Kollias and Kalivas, 1998), and MicroLEIS (De la Rosa et al., 2004).

LandSuit (Samranpong and Ekasingh, 2002) is an agro-economic land evaluation decision support system at the provincial level. AgZone (Ekasingh et al., 2005), a spatial decision support system using a land evaluation framework, has been developed for agricultural zoning in Thailand.

Given the many uncertainties and changes in agricultural production and trade in competitive markets across a region, the aim of this study was to create a system that supports dynamic assessments of economic land use planning for major crops in Northern Thailand. The system consists of various components and analyses to facilitate effective use of large scale databases and to provide different tools for implementing necessary steps for efficient physical and economic land evaluation. A customized user interface has been designed to handle spatial data management and analysis functions provided by GIS.

2. The study area

Three provinces in northern Thailand were selected as the study areas. These are Chiang Mai, Chiang Rai, and Lamphun; cover 38,156 sq. km, and the land extent lies between 17° 14’ 23” to 20° 27’ 33”N and 98° 3’ 6” to 100° 35’ 4”E. The provinces are diverse in topography with highlands, uplands and lowlands. Irrigation facilities are usually available in the lowlands. In the wet season, paddy rice is the predominant crop in the paddy areas. In the uplands, maize, and fruit trees are grown. Longan (Dimocaropus longan), mango (Mangifera indica), lychee (Litchi chinensis) and tangerine (Citrus reticulata) are major types of the fruit trees grown. Coffee and tea are also popular crops in the highlands. In the dry season in the lowlands, a second crop e.g. soybean, garlic, shallot, potato, tomato and cabbage are grown. Farmers are mostly small semi-commercial farmers with farm sizes of 1–2 ha.

For the land evaluation, economic data were collected on farmers’ use of materials, yields, material costs and crop prices. A total of 1600 households in 35 districts were covered. Data include attributes of land use, agricultural production, factors of production, prices, costs, returns and economic efficiency of land and water use. Data on 26 crops produced by farmers during 2001–2003 were included. Time series data were collected for price data (1998–2002) and irrigation water (1992–2003). Geodatabase, a relational spatial database implemented by ESRI (Zeiler, 1999), was designed and developed to collect technical coefficients and price variables.

3. Physical land evaluation

Land mapping units (LMU) are defined as homogeneous land area with respect to key land attributes. The LMU was used as a basic unit for land evaluation and created by overlaying various map layers including soil, rainfall, temperature, and irrigated area. Land characteristics (LC) derived from attributes of the above map layers were matched with land use requirements (LUR) of selected land utilization types (LUT).

A physical suitability index was constructed using the FAO Framework (FAO, 1976) and the Project fuzzy land evaluation program (Samranpong and Ekasingh, 2003). This program implemented fuzzy membership function determined using S-membership functions (Robinson, 2003; Sicat et al., 2005) which are appropriate and robust for both quantitative and linguistic variables,
to calculate land qualities. The S-membership functions for x attributes can be defined as:

\[
S(x, \alpha, \beta, \gamma) = \begin{cases} 
0, & x \in (-\infty, \alpha] \\
2((x - \alpha) / (\gamma - \alpha))^2, & x \in (\alpha, \beta] \\
1 - 2((x - \beta) / (\gamma - \alpha))^2, & x \in [\beta, \gamma] \\
1, & x \in [\gamma, +\infty] 
\end{cases}
\]

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0, & x \in [\gamma, +\infty] 
\end{cases}
\]

Eqs. (1) and (2) represent, respectively, increasing and decreasing fuzzy membership functions for x attributes (e.g., soil depth for increasing and slope for decreasing) representing a factor S. Here \( \alpha \) and \( \gamma \) are lower and upper limits of x attributes, and \( \beta \) is \((\alpha + \gamma)/2\). The details of \( \alpha \), \( \beta \), and \( \gamma \) were modified from Tansiri and Saifak (Tansiri and Saifak). Membership function values were then combined using a convex combination operation to calculate a Joint Membership Function (JMF) (Baja et al., 2002a; Burrough, 1989; Urbanski, 1999) for each LMU, as follows:

\[
\text{JMF}(X) = \lambda_1 S(x_1) + \lambda_2 S(x_2) + \cdots + \lambda_n S(x_n)
\]

where JMF(X), \( \lambda_1 \), \( \lambda_2 \), \( \cdots \), and \( S(x_1), S(x_2), \cdots, S(x_n) \) range from 0 to 1; JMF(X) is Joint Membership Function for all variables within LMUs considered. \( \lambda_1 \), \( \lambda_2 \), \( \cdots \) is weighting factor for each decision criterion and \( n \) indicates the number of attributes considered within each group of variables.

Land utilization types (LUT) were defined for the crops under investigation, then land use requirements (LUR) such as planting periods, duration of the crops, management practices and water sources were specified. Management levels were grouped into three levels, high, medium, and low. In the high management level, farmers may invest heavily in fertilizer, pesticide, or labor to reach the highest yield, while farmers who have low capital will select the low management level, producing a lower yield. The medium management level is assumed for a general agricultural practice. For dry-season crops, the land evaluation system is able to determine automatically whether irrigation water was available. Land quality (LQ) was then evaluated from LCs with reference to the LUR of each LUT before computing a final suitability. LUR was defined within a specific production system LUT. Any function for evaluating the corresponding LQ was also LUT-specific. By using the fuzzy land evaluation technique, the set of LQ and suitability indices were treated as continuous numbers ranging from 0 (least suitable) to 1.0 (most suitable) (Fig. 1).

4. Economic land evaluation

Economic land evaluation can be quantified after the physical suitability index has been obtained. The concept of the evaluation, implemented in the so-called EconSuit system, was based on the principle of Dent and Young (Dent and Young, 1981) and a procedure reported by Rossiter (1995) to estimate net returns for each LMU (Fig. 2).

Economic input zones were created to group survey samples into homogenous zones within which production costs and output prices were similar. This was accomplished using functions in GIS to create Voronoi polygons from sampling points used in the farmers’ survey. For example, individual polygons displaying the economic input zones for garlic can be divided into 2 zones, namely IGL01 and IGL02, containing attributes of data on production factors such as one-time costs (e.g., land preparation machinery, growing machinery), variable costs (e.g., fertilizer, pesticide, labour, energy), maximum yields, and output prices.

Expected yields in the EconSuit were obtained by multiplying the optimal yield with proportional yield factors. The optimum yield is not a biological maximum but rather a realistically maximum attainable yield recorded in field survey results in the study areas (Ekasingh et al., 2004) assuming normal management conditions and no removable limitations. The physical suitability index which directly affected crop yields was used as a proportional yield factor. Estimated yield for a given LUT for each LMU was then calculated. Expected total revenues were estimated by multiplying expected yields by a given output price.

In terms of costs, total costs of production varied with each LUT. The total costs consisted of production costs and land improvement costs which depended on severity levels of land quality in the LMU. A severity level represents the degree of limitation on the land to achieve optimal land quality (Rossiter and Wambike, 1997). It is a classification of the LQ, indicating the degree of limitation or hazard associated with the LQ on a particular land area, from ‘no limitation’ upward to ‘maximum’. Since there was spatial variation among production costs in different zones of the study areas, data on cost of production were stored for different zones. However, the costs may be updated by users when new information becomes available. Production costs were then subtracted from total revenues giving expected net returns. Once expected net returns for LMUs were estimated, they may be classified into economic suitability classes by users to match different production goals of LUTs. The results of economic land evaluation may be displayed and printed as maps of different sizes.

The EconSuit system was designed to help automate the evaluation of economic suitability of LMUs. The system was developed in Visual Basic and Component Object Model Technologies (COM) that works with ArcMap9.x. It would facilitate users to select target areas and LUTs to be evaluated. The users may verify details of input costs and output prices, edit them as required when new information becomes available. The program will estimate expected net returns for each LMU, and display the resulting economic suitability maps.

Figs. 3 and 4 show how EconSuit works, where the first step is the selection of LUT. In the software, a window for selecting LUT and its suitable zone from which details of production costs and output prices giving expected net returns for each target area is obtained. Once expected net returns for each LMU are displayed in the window, the users may verify details of input costs and output prices, edit them as required when new information becomes available. The program will estimate expected net returns for each LMU, and display the resulting economic suitability maps.
price is displayed (Fig. 3a). In this example, the user selected garlic (dry season, irrigated, and average level of management) and economic inputs Zone2 (ILOL2) for evaluation. Voronoi polygons of the selected economic input zones may be displayed on the screen for preview (Fig. 3b). Data from the original survey were used as default values in the program for an individual zone.

In order to cope with changing economic conditions, a user interface was designed to facilitate updating of one-time costs (Fig. 4a), technical coefficients and unit prices of variable inputs (Fig. 4b). The maximum (S1) yield and the output prices may be updated to reflect the best estimated values obtained from the better sources of information (Fig. 4c). Once data are updated, economic costs and returns will be recalculated. The users may define class limits for net returns in each economic suitability class; the program will use these values for delineating LMUs into economic suitability classes for map displays.

5. Results: physical and economic suitability

5.1. Physical suitability

Different LUTs can be considered and used to create physical suitability maps for different crops that require different planting periods, water sources, management levels and biophysical properties. The example in Fig. 5 illustrates the physical suitability index for four different LUTs in the area surrounding Chiang Mai province. This flood plain and poorly drained area has high suitability for wet season rice which needs inundation during growing period (Fig. 5a). The inundated condition affects the suitability of wet season soybean causing the suitability index drop to nearly zero (Fig. 5b). When soil condition passes from an excess of water to dry condition, dry season soybean is assessed as having high suitability (Fig. 5c). A drainage system implementation scenario was applied for longan. The model shows a strong response to a changing of growing condition by displaying highly suitable for growing longan in poor drain areas (Fig. 5d).

5.2. Economic suitability

The results of socioeconomic land evaluation EconSuit are sensitive to changes in production cost and crop price parameters. Given an LMU with physical suitability rating of S1 (highly suitable), the expected yield is always high. However, the expected net return is sensitive to change in cost of inputs and output prices. Therefore, the economic suitability rating or the expected net return of this piece of land is not always highly suitable. This can be illustrated from the spatial distribution of net economic returns of LMUs estimated from the economic land evaluation procedures described above. Changes in economic suitability rating of the LMUs are illustrated for garlic, where prices decrease from 6.0 Baht/kg (Fig. 6a) to 5.0 Baht/kg (Fig. 6b).

The dynamic nature and capability of EconSuit can be used as a tool for scenario analysis, particularly when one wants to explore alternatives for the replacement of crops which may be severely affected by the country free trade agreements (FTA) or future unexpected forces. For instance, suppose that a trade agreement may cause the price of garlic to fall to 4.0 Baht/kg, the EconSuit system will be able to identify the areas where garlic cultivation would not be profitable. It will further update net returns of each crop in the database, rank them and list the net return details and those cultivated areas of the ones that would be more profitable than garlic at the price of 4.0 Baht/kg (Fig 7a). Users can then select the crops of their choice to replace garlic for specified cultivated areas. Fig. 7b displays the areas where alternative crops are allocated for the choice of soybean and maize. Other scenarios such as an expansion of existing crops may be also explored. In this case, the users specify the crops and areas to be expanded through the graphic interface. The program will compare net returns of the alternative crops to those of existing crops and automatically assign the target crops to designated areas. EconSuit has the capability to evaluate the economic potential of different land use options whether in a monocropping or multiple cropping systems. Economic returns can be predicted and displayed in maps. Such visual effects will help land use planners to do land use planning according to market demands. Action plans for a particular area can be reviewed by farmers and local officers to make them aware of alternatives and adaptability to cope with economic circumstances. Scenarios of land use options and market volatility can be undertaken to assess the sensitivity of profit levels. In this way, the GIS system can be made to respond to economic dimensions and can support decision makers in future land use planning in a more efficient, dynamic and relevant manner. Maps

Fig. 2. Conceptual diagram of economic land evaluation, EconSuit.
provided by the system generated from different scenarios can assist both farmers and land use planners to communicate with each other effectively. Land quality conservation can also be facilitated through this system.

6. Discussions and conclusions

The dynamic and competitive nature of agricultural production requires economic and physical assessment of land using spatial modelling. The system described in this paper utilizes GIS functions and capability to store and process biophysical as well as economic data for assessing economic suitability of land for specific uses in agriculture. The system utilizes fuzzy membership functions to express and combine quality of land into a physical suitability index. This in turn is used to estimate yield and economic suitability of land by integrating information gathered from the field survey.

The use of physical land suitability indices for estimating crop yields and production reduces the demand for identifying the many parameters that are usually required in crop models. The Decision Support System for Agrotechnology Transfer (DSSAT) is computer software integrating the effects of soil, crop phenotype, weather, and management options then simulate outcomes of crop management strategies for 16 different crops (Jones et al., 2003). Rice models (Jintrawet, 1995), sugar cane models (Promrit and Jintrawet, 2001) and peanut models (Banterng et al., 2004) are currently accessible under the DSSAT shell. In those models, genetic coefficients for different cultivars are used as model inputs to describe crop phenology in response to temperature and photoperiod. Crop yields are simulated using soil data and daily weather data. Genetic coefficient and solar radiation are the weakness of crop models in terms of data obtainability.

A key feature of this decision support system is that it provides a structure for representing the interactions between a crop prediction model and economic model for general purposes such as those in Letcher et al. (2007). Although the estimates using this method are not as fine and detailed as those used in crop models, the procedure enables faster and wider coverage of crops. It enables the inclusion of economic variables. The economic land evaluation, based on physical land evaluation, is relevant to decision makers as it includes economic returns of land use. It can be used to compare different crops and land use and thus facilitates land use planning. Moreover, its graphic user interface in the Thai language, as with LandSuit (Samranpong and Ekasingh, 2002) and AgZone (Ekasingh et al., 2005) allows the flexibility for selecting target areas and land use types, and for updating all economic parameters necessary in the economic land evaluation process, unlike other models such as FUZZYLAND (Kollias and Kalivas, 1998) and ALES (Rossiter and Wambeke, 1997). This enables the system to incorporate changes in economic variables. Land use planners can utilize it to predict and plan future land use effectively. Impact can be observed on activities that are directly affected by change. It facilitates timely and relevant analysis. Nevertheless, land suitability indices should be
Fig. 4. User interfaces for updating (a) one-time costs, (b) variable costs, and (c) maximum yield and output price.
continually refined and verified with field level data for best results.

The fuzzy set methodology used for yield prediction still requires adequate knowledge of the mechanisms relating crop responses to land characteristics. In using a multiplication function, the selection of criteria weights must be taken into account carefully because the weights can have a major effect on results. This weighting can be undertaken by integration with other technique such as AHP-MCDA (Hill et al., 2005) to improve model outcomes.

Even though the EconSuit system is helpful for planners and decision makers in finding alternative land use options to cope with rapid market and policy changes, further refinement is necessary to improve spatial interpolation and integration of socioeconomic and biophysical data. Extension of this approach to generate zones of suitable economic crops could be explored. Continual updating of information on costs and prices in the system is also encouraged. Our approach to economic land evaluation separates input-output coefficients, which are more robust, from price data, so that the
Fig. 6. Displays of results in EconSuit: spatial distribution of expected net return of irrigated garlic in the dry season at the output price of (a) 6.0 Baht/kg (b) 5.0 Baht/kg.
Fig. 7. An interface for setting scenario to replace garlic areas with areas of alternative crops.
updating process is not arduous. Although it would be ideal to have location-specific prices of outputs and inputs and costs of production, at most times the scarcity of economic data is a major constraint which hinders such an attempt at disaggregation.

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