An Integrative Agricultural Land Evaluation and Classification for Sustainable Land-use in Uthai Thani Province

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Abstract

This study investigated and evaluated the suitability of agricultural land use taking into account the physical, socioeconomic and environmental conditions in order to make a soil conservation-oriented land use planning for Uthai Thani Province, Thailand using Geographic Information System (GIS) technology together with the Two-stage Land Evaluation Approach, Universal Soil Loss Equation (USLE), macro nutrient loss assessment, and linear programming techniques. Physical land suitability evaluations for major present and alternative land utilization types were performed. Predicted potential soil erosion (PE) and actual soil erosion (AE) volume in agricultural land under present land cover management and alternative crop types were measured. Then, the predicted actual soil loss together with nutrient availability data of each soil type were used to calculate the macro plant nutrient loss in the form of Urea, Super Phosphate, and Potassium Chloride in each soil series under alternative crop types. The overall land suitability assessment using linear programming was conducted using two postulates - minimizing macro nutrient loss while maintaining current levels of average net farm income and maximizing net farm income while not exceeding current levels of macro nutrient loss. Results indicate that even though most of the soil types in the study area are not fertile, changing farming patterns from intensive mono-crops to fruit trees may provide more profitable and sustainable returns in approximately 25% of the total agricultural area. Some alternative crops including coffee, cocoa, vegetables, and rubber would not be recommended for the study area because of severe limitations of the soils. The results also revealed that approximately 41,500,000 tons of soil are annually lost from agricultural land of the province with 8.95% and 4.52% of the area under severe and very severe erosion while the total actual losses of urea, super phosphate, and potassium chloride were estimated at 90,005.70, 2,761.96, and 7,394.57 tons/year respectively.

Keywords: Land Evaluation, Integrated Land Use Planning, Erosion Hazard, Soil Loss, Nutrient Loss, GIS, Linear Programming

1. Introduction

Up to the year 1950, the increase in world food production was based largely on the expansion of croplands, but in 1950s, yields had increased dramatically due to the increasing use of energy, expanding irrigation area and applying more fertilizer. Since the 1960s, the Green Revolution based crucially upon high yielding varieties (HYVs) of cereals and its accompanying technologies, has widely been promoted around the world, leading to complicated problems such as reduced crop diversity through intensive mono-cropping systems, increasing the threat from pests, drought, and other environmental shocks and stresses [1].

Agricultural intensification has also led to increased soil erosion and lower soil fertility [2], and soil organic matter loss [3]. Consequently, soil erosion has been perceived, in much literature, as one of the principal land degradation processes resulting in lowering environmental quality and growing social and economic impacts [4-6].

Sustainable agriculture has been introduced to ease the adverse effects of intensive agriculture because its ultimate goal is to develop farming systems that are productive and profitable, conserve the natural resource base, protect the environment, and enhance health and safety over the long-term [7-10]. Among the means to achieve sustainable agriculture, soil erosion and nutrient loss control were suggested owing to the fact that the soil is one of the most essential components of the agroecosystem.

Besides, to ensure the global food security, the World Bank emphasizes fostering the growth of national and global food supply so that hunger can be eliminated. Therefore, countries worldwide will need to raise the productivity of agriculture. This must come primarily from raising biological yields rather than expanding or intensifying the cultivation area because most fertile lands have already been under cultivation and people everywhere are also increasingly concerned about the environmental impacts of adding new units of land into agricultural production [11]. Therefore, raising yields by optimizing the use of agricultural land without damaging the environment and resource base is a real challenge.

According to Thai agriculture, evidence has shown that farming patterns in Thailand are still based largely on mono-cropping practices with a large amount of agrochemical use, natural resources degradation, and too much pollution [12]. Not only have field crops led to land degradation problems in term of surface erosion, toxic soil, soil nutrient loss, etc. but also soil fertility has declined rapidly within a few years because most field crop areas are located on slopes where nutrients are lost by leaching and runoff [13].

Indeed, top-down agricultural plans plotted by government agencies, which have currently been used in all parts of Thailand, are still based on the balance of land supply and demand for agricultural commodities rather than the socioeconomic background and environmental factors in each area. Therefore, this kind of planning process is probably not able to meet the philosophy of the new agricultural production planning approach which emphasizes productive, profitable, and environmentally sound farming practice. Moreover, it might not solve the above mentioned-problems of Thai agriculture, which currently needs production plans that ensure economic return while maintaining the resource base and protecting the environment at the same time.

Consequently, this study endeavors to conduct an integrated agricultural land-use planning which is based upon the ability to manage agroecosystems to meet social and economic need, to sustain land productivity and profitability, as well as to maintain the resource base in the study area. The geographic information system (GIS), Universal Soil Loss Equation (USLE), Two-stage Land Evaluation Approach suggested by FAO, and Linear programming models were used to evaluate overall land suitability by simulating physical, environmental and economic factors of the study area together as the integrated analysis.

Uthai Thani province was selected as the study area since more than 90% of its agricultural land has been used for only five cash crops widely proved as an unsustainable agricultural system. Most of agricultural lands in this area are not fertile with other problems, such as shallow soil, sandy soil with low water retention and low fertility, flooding in rainy season, and draught during cultivating period, etc. [14]. So, sustainable agricultural land use should be introduced for this area.

2. Materials and Methods

2.1 Land suitability evaluation

Land suitability evaluation was made on approximately 2.078 million rai or 0.332 million hectare of agricultural land covering about 49.40% of the total area of Uthai Thani province. Two-stage Land Evaluation Approach suggested by FAO [15], which land qualities and characteristics of each land unit were matched with crop requirements and limitations, was applied. In order to obtain suitability classes including very well suited (S1), well-suited (S2), moderately suited (S3), poorly suited (S4), and not suited (N), an arithmetic procedure suggested by FAO [16] was also used.

In this process, the suitability class scores as S1 = 1.0, S2 = 0.8. S3 = 0.5, and N = 0.0 were assigned. These value were multiplied for all 12 land qualities comprising soil texture, soil drainage class, rooting condition, nutrient retention (CEC), pH, organic matter availability, available P, available K, slope, temperature, dry month, and annual rainfall. Product of the multiplication was converted to an overall suitability classes which are 0.8 -1.0 = S1, 0.4 – 0.8 = S2, 0.2 – 0.4 = S3, > 0.0 – 0.2 = S4, and 0.0 = N, respectively.

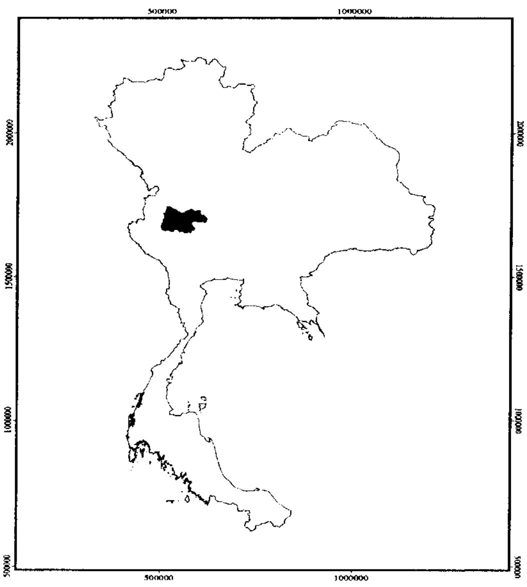


Figure 1. Study Area (Uthai Thani Province)

The crucial data about crop requirements and land suitability rating by land qualities were reviewed mainly from Navanugraha et al. [17] and Navanugraha [18] while digital soil maps and soil inventory data obtained from the Department of Land Development were used as materials for this process. This study selects 5 major current crops including wetland rice, maize, cassava, sugarcane, and pineapple and 11 alternative crops comprising general fruit trees, mango and jackfruit, longan, soybean, coconut, coffee *(Arabica)*, cocoa, vegetable, para rubber, eucalyptus and fast-growing trees, and pasture, to evaluate with the 43 grouped land units from 67 soil series in the study area. The results of land suitability classes for these 16 crop types were presented in from of tabular figures and suitability maps.

2.2 Soil erosion hazard assessment

The Universal Soil Loss Equation (USLE) was employed to estimate the potential erosion (PE) and actual soil erosion (AE) value of each land unit map as the following equation:

$$PE = RKLS$$

where PE is potential soil loss based on the assumption that there are no conservative practices (P = 1) and the soil is bare (C = 1) (t/ha/year).

R is the rainfall erosivity factor using the regression equation suggested by the Department of Land Development [19] as R = 0.866 Ra -323.01, where R is annual erosivity in t/ha/year and Ra is annual rainfall (mm).

K is the soil erodibility factor estimated from soil monograph deriving from regression equation below:

$$100K = 2.1\ M^{1.14}\ (10^{-4})(12-a) + 3.25(b-2) + 2.5\ (c-3)$$

where M = (percent of silt + very fine sand) * (100-percent clay)

a = percent organic matter,

b = structure code,

and c = profile permeability class

LS is the slope length index using LS equation developed by Wischmeier and Smith [20] as follow:

$$LS = [(\text{length (m)} / 22.13)^{0.5}] * [\ 0.065 + 0.0456\ (\%\ \text{slope}) + 0.006541\ (\text{slope})^2]$$

To calculate this LS factor, the digital elevation contour map of the study area was processed using PC TIN (Triangulated Irregular Network) to get slope angle and steepness of the slope throughout the study area. The values of LS factor mapped out as a GIS coverage were then computed by the above equation. Computed by overlaying R factor, K factor, and LS factor using the Arc View GIS computer software, the result of potential soil erosion (PE) was obtained.

Then, the actual soil loss (AE) was calculated by combining the potential soil loss (PE) with crop management factor (C factor) obtained from literature [21-23] as the following equation:

$$AE = RKLSC$$

The C factor was applied to current land cover map interpreted by the Royal Forest Department [24] that was verified by ground truth for producing a GIS coverage of C factor map.

2.3 Macro nutrient loss assessment

Due to the fact that soil erosion represents a major cause of on-site nutrient loss, the volume of soil loss can be used to estimate the macro nutrient or major nutrient elements (N,P,K) loss of the study area. This will help estimate environmental attribute loss, which is normally non-marketed goods occurring along with the farming practices, in terms of money value.

In this study, the nutrient loss was employed as one of the principal variables in analyzing the optimal land use planning using linear programming technique. In order to obtain the predicted macro nutrient loss, nutrient availability database, particularly available organic matter appearing in percentage of the total soil weight, available phosphorus and potassium in ppm, collected from the soil survey report published by the Department of Land Development [25] were used. These nutrient availability were applied to calculate the macro nutrient loss in terms of urea, super phosphate and potassium chloride by the following formula [26-27]:

-One unit of organic matter makes 0.1087 unit of urea fertilizer.

-Quantity of super phosphate fertilizer is equal to 5.729*available phosphorus.

-One unit of potassium chloride fertilizer is equal to 2.0077*available potassium.

2.4 Overall land suitability assessment using Linear Programming Models

The overall land suitability assessment using linear programming model, which integrates the physical land suitability, macro nutrient loss as environmental condition, and net farm income as economic condition, together in the simulation process were developed as follows:

2.4.1 The optimal land use planning under the condition of minimizing macro nutrient loss, subject to current net farm income (option 1)

For this option, a linear programming model was designed as follow:

a) The objective function, Z, is "minimizing the overall macro nutrient loss" caused by each current land utilization types on each soil series.

b) Constraints or limiting factors are the amount of land available of each soil series and average net farm incomes of each soil series. These are fixed at the existing level.

c) Coefficients are the amount of net farm incomes and total NPK loss, in terms of urea, super phosphate, and potassium chloride, incurred in each land utilization type and on each soil series. In this regard, net farm income figures obtained in each land unit were converted to be those of soil series. However, the land units, that were not selected as the target in the data collecting process for the five current land utilization types because of very small growing area, were assigned to have average net farm income among the targeted areas.

d) Decision variables

The combination of five current land utilization types including wetland rice, maize, cassava, sugarcane, and pineapple, were assigned as farming activity variables. Thus, the amount of land which are expected to be used for each farming activity appears to be the decision variable in the model.

Thus, the linear programming model in from of algebraic equation was set as follows:

where: Z = summation of the amount of plant nutrient loss from urea, super phosphate, and potassium chloride in kg incurred from farming activities "j" of the objective function

$$\text{Minimize} \quad Z = \textstyle\sum_j c_j X_j \qquad j = 1,2,3\ldots5 \qquad \text{-----(1)}$$

$$\text{Subject to:} \quad \textstyle\sum_j a_{ij} X_j \leq L_i \qquad i = 1,2,3\ldots67 \qquad \text{-----(2)}$$

$$\textstyle\sum_j b_{ij} X_j \geq M_i \qquad i = 1,2,3\ldots67 \qquad \text{------(3)}$$

$$X_j \geq 0 \qquad \text{------(4)}$$

X_j = production level in rai (1,600 square meters) for farming activity "$_j$"

j = 1 represents farming activity of wetland rice
j = 2 represents farming activity of maize
j = 3 represents farming activity of pineapple
j = 4 represents farming activity of cassava
j = 5 represents farming activity of sugarcane

M_i = average net farm income in Baht of doing five farming types (for j = 1 to 5) on the whole area of soil series type "$_i$"

c_j = coefficient represents total amount of urea, supper phosphate, and potassium chloride losses in kg from farming activity "$_j$"

a_{ij} = coefficient represents the amount of land in rai (1,600 square meters) of soil series type "$_i$" that are occupied by farming activity "$_j$"

L_i = total area in rai (1,600 square meters) for soil series type "$_i$"

b_{ij} = coefficient represent the amount of net farm income in Baht of doing farming activity "$_j$" on an area of one rai of soil series type "$_i$"

2.4.2 The optimal land use planning under the condition of maximizing net farm income, subject to current levels of macro nutrient loss (option 2)

In this option, the linear programming model was almost the same as option 1 in general design. However, the objective function and limiting factors were alternated to see, in contrast, "if there is any change in the optimal condition of the land use when maximizing net farm income is put as the objective function while minimum environmental attributes loss is required".

3. Result and Discussion

3.1 Land suitability classification

The output of this process resulted in suitability rating scores of each crop on each land unit which were, in turn, converted to suitability classes, namely very well suited (S1), well-suited (S2), moderately suited (S3), poorly suited (S4), and not suited (N). These suitability classes were converted into maps codes and linked with soil maps by GIS technique.

Finally, soil suitability maps were produced and the amount of areas under each suitability class of the total 16 land utilization types (LUTs) were computed and reported in tabular form. The percentage of growing area for each suitability class and each land utilization type is shown in Table 1.

Since most soil types in the study area are not fertile, resulting in 33 soil series classified under low fertility class, 26 series were under the medium fertility class, while only 4 series were in the moderately high fertility class and only the remaining 4 series were in the high fertility class. Most of lands could be classified as not suitable for agriculture in terms of physical conditions themselves.

As shown in Table 1, there are only 4 crop types, namely maize and sorghum, pineapple, soybean, and cassava having very well suited area (S1), but only in small proportion. Furthermore, no piece of land is classified under class S1 for all kinds of fruit trees. There is approximately 10% and 30% of the total area for agriculture, which were classified, in a collective view, as well-suited area (S2) and moderately suited area (S3) while about 45% and 13% of the total areas for agriculture were, in general, classified under poorly suited (S4) and not suited (N) areas.

Principal limitations, which in general are moderately severe for sustained cereal production in the study area, include dry month, average annual rainfall, temperature, nutrient retention, and nutrient availability. Fortunately, these limitations can be corrected with existing knowledge by fertilizer application, sprinkling systems, sunlight subsidence, and crop management that can upgrade the suitability class and increase productivity and profit to the lands. However, the lands have limitations which can probably be surmountable in time but cannot be corrected with existing knowledge at currently acceptable costs including soil texture, soil drainage, and rooting condition.

3.2 Soil erosion hazard assessment

Using overlay technique for factor R, K, LS, and C, the estimated soil loss volume is presented in Table 2 below.

Table 1. Proportion of suitable areas for 16 LUTs in the study area

Land utilization types	Class S1 (%)	Class S2 (%)	Class S3 (%)	Class S4 (%)	Class N (%)
1. Wetland rice	0.00	1.41	15.48	52.67	30.44
2. Maize and Sorghum	9.23	16.24	54.31	20.22	0.00
3. General fruit trees	0.00	9.32	8.69	57.95	24.04
4. Mango and Jack fruit	0.00	10.94	10.02	56.17	22.87
5. Longan	0.00	10.76	18.36	57.20	13.68
6. Pineapple	5.93	2.71	28.24	59.09	4.03
7. Coconut	0.00	8.81	46.34	31.17	13.68
8. Soybean	9.23	16.24	54.31	20.22	0.00
9. Cassava	0.09	36.92	27.93	18.58	16.48
10. Sugarcane	0.00	16.20	6.80	69.12	7.88
11. Coffee (Arabica)	0.00	5.93	10.29	70.10	13.68
12. Cocoa	0.00	10.25	17.21	49.67	22.87
13. General vegetables	0.00	0.00	20.23	56.53	23.24
14. Para rubber	0.00	0.00	8.64	75.77	15.59
15. Eucalyptus and fast-growing trees	0.00	14.70	67.77	15.51	2.02
16. Pasture	0.00	12.75	70.71	16.54	0.00

3.3 Macro nutrient loss

The actual macro nutrient loss under current agricultural land use types in the form of urea, super phosphate, and potassium chloride of the study area were estimated at 90,005.70, 2,761.69, and 7,394.57 tons/year respectively. Since the estimated volume of macro nutrient loss varied according to the volume of actual soil loss and nutrient availability of each soil series, every success in soil erosion control might lead to a success in macro plant nutrient conservation in the study area as well. These will help reduce the vast amount of environmental attribute loss that can be directly converted into monetary term and also mitigate the environmental deterioration caused by runoff and contaminated ground water from agricultural areas.

Table 2. Estimated Actual Soil Loss (AE) Classes of Uthai Thani Province

Erosion Class/[1]	Erosion Rating (t/ha/y) [1]	Actual Soil Loss (t/y)	Area[2]		Average (t/ha/y)
			Ha	%	
Very slight	<6.25	361,406.34	125,692.16	42.84	2.88
Slight	6.25-31.25	1,257,293.17	90,530.16	30.86	13.89
Moderate	31.25-125	2,408,664.41	37,644.05	12.83	63.99
Severe	125-625	7,529,507.46	26,268.67	8.95	286.63
Very severe	>625	30,136,542.99	13,268.97	4.52	2,271.20
Total		***41,693,414.37***	***293,404.01***	***100.00***	

Note: [1] Standard suggested by Department of Land Development [25]
[2] Excluded forest land (F), Miscellaneous land (M), Urban and Built-up land (U), and Water bodies (W)

3.4 Overall land suitability assessment using Linear Programming

Linear programming technique was used to assess the overall land suitability, which integrates the results of physical land suitability (the LUTs that were classified as S3, S2, and S1 in each soil series), macro nutrient loss as environmental condition, and net farm income as economic condition, together in the simulation process.

The results of option 1 model show that if minimum macro nutrient loss is set as the objective function for doing farms while the average net farm income level is needed to be maintained at not less than the current level, the most suitable crop combination is suggested as growing wetland rice, maize, sugarcane, cassava, and pineapple at the proportions of 2.72%, 54.90%, 0.45%, 19.54%, and 22.40% of the total agricultural area respectively.

On the other hand, if maximum net farm income is set as the objective function for doing farms while the average macro nutrient loss is needed to be maintained at not more than the current level (option 2), the most suitable crop combination is suggested as growing wetland rice, maize, sugarcane, cassava, and pineapple at the proportions of 1.16%, 42.49%, 1.11%, 19.95%, and 35.29% of the total agricultural area respectively.

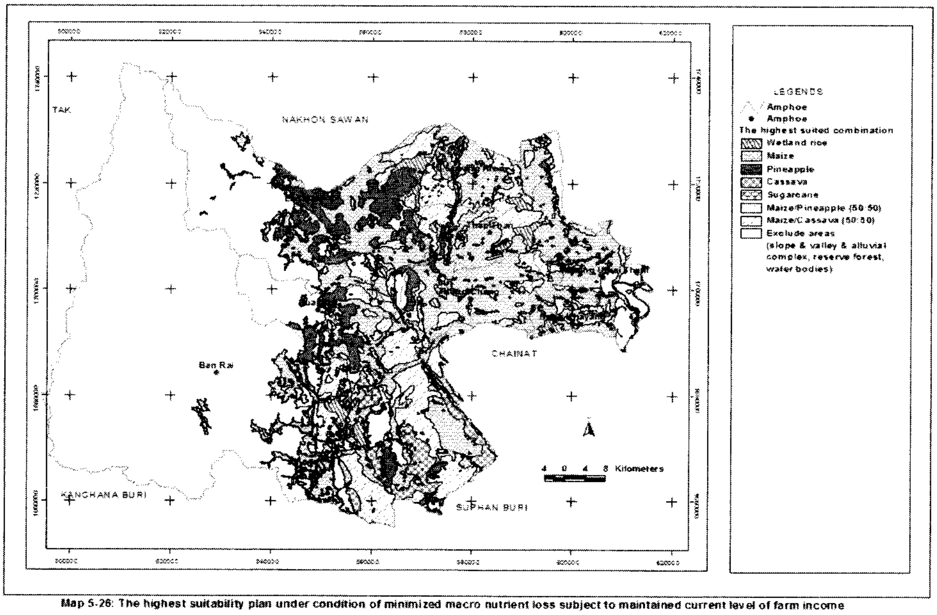
In addition, to map out the optimal farming plans in both cases, the farming plan under the condition of minimizing macro nutrient loss with respect to maintaining the current level of net farm income and the farming plan under the condition of maximizing net farm income subject to maintaining the current levels of nutrient loss, the coincident matrix technique was applied to select the highest suitable crops for each land unit map.

Results of the first case show that the area for growing wetland rice, maize or sorghum, pineapple, cassava, and sugarcane is approximately 10,581.97, 144,777.75, 34,866.36, 21,989.84, and 559.83 ha covering the percentage of 3.61, 49.34, 11.88, 7.49, and 0.19% of the total area for agriculture, respectively. Besides, dual crop types that would be recommended to grow at 50%:50% proportion in the same soil types are maize and pineapple in 10,660.99 ha covering 3.63% of the total area and maize and cassava in 70,009.75 ha covering about 23.86% of the total area. The location of growing these crops can be shown in Figure 2 below.

According to the second case, the result illustrates that the area for growing wetland rice, maize or sorghum, pineapple, cassava, and sugarcane is approximately 2,404.82, 57,476.78, 127,446.28, 26,667.97, and 2,825.28 ha covering the percentage of 0.82, 19.59, 43.43, 9.09, and 0.96% of the total area for agriculture, respectively. Moreover, dual crop types that would be recommended to grow at 50%:50% proportion in the same soil type are maize and pineapple in 10,660.99 ha covering 3.63% of the total area and maize and cassava in 65,926.36 ha covering about 22.48% of the total area. The location of growing these crops can be shown in Figure 3 below.

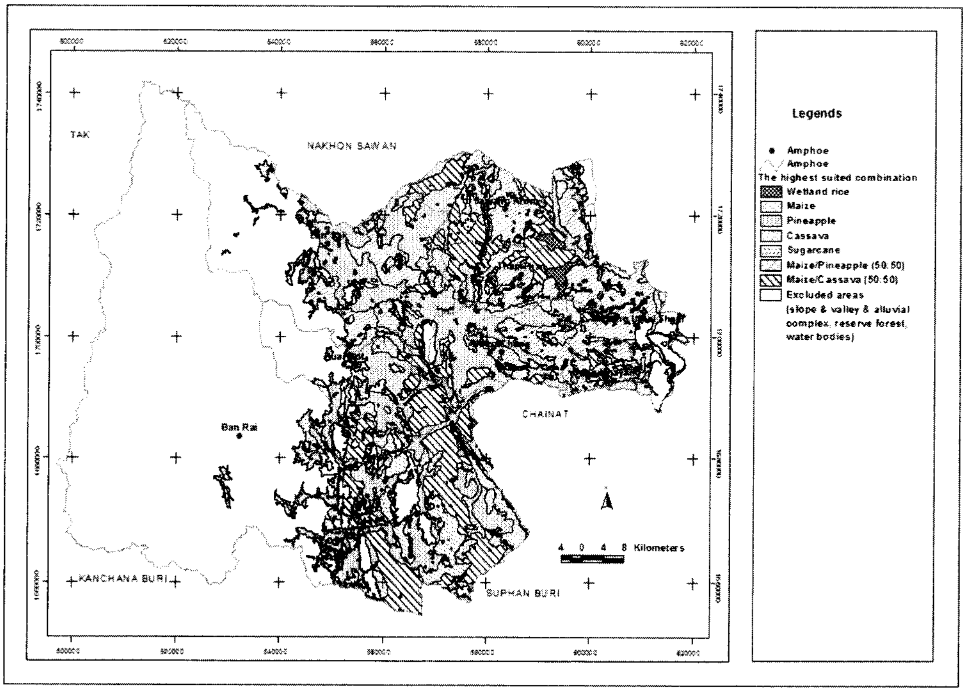
4. Recommendations

In order to obtain the most effective agricultural land use plan for a province, a soil database should be made for the areas under reserved forest, alluvial complex, slope complex, and land in use by farmers. This will help to analyze the soil erosion hazard and other related topics based on soil qualities and characteristics covering the entire area of the province. Besides, the plan for soil conservation practices in Uthai Thani province should be urgently run under consideration of less environmental or ecological changes in order to mitigate soil degradation from soil erosion and environmental attribute loss. Furthermore, the physical suitability maps for fruit trees can be used to promote growing some kinds of fruit trees in some parts of the province where there appear to be well-suited and moderately suited areas. This will be useful for plan-makers in the province to assist the farmers who want to change their farming practices from growing intensive mono-crops to orchards that are expected to gain more benefits and be a more sustainable environment.



Map 5-26: The highest suitability plan under condition of minimized macro nutrient loss subject to maintained current level of farm income

Figure 2. The highest suitability plan under condition of minimized macro nutrient loss, with maintaining the current level of net farm income



Map 5-27: The highest suitability plan under condition of maximized farm income subject to maintaining the current level of macro nutrient loss

Figure 3. The highest suitability plan under condition of maximized farm income, with maintaining the current level of macro nutrient loss

Finally, the areas under severe and very severe erosion should be intensively cared for by the policy-makers. Close cooperation between local agricultural officers and the farmers should be commenced in conserving end enhancing the quality of this resource base.

5. Acknowledgments

Special words of thanks goes to Prof. Dr. Niphon Tangtham for valuable suggestions and contributions to this study that made this study possible. The authors would also like to express sincere gratitude to the Asian Development Bank (ADB) for financial support, which helped this research toward successful completion.

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