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Farmer or Expert; A Comparison between Three Land Suitability Assessments for Upland Rice and Rubber in Phonexay District, Lao Pdr

Juan Francisco Sánchez-Moreno[1*], Abbas Farshad[1] and Petter Pilesjö[2]

[1] *ITC, Enschede, The Netherlands*
[2] *Associate Professor. Director GIS Centre. Lund University, Sweden.*

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ABSTRACT Around 80% of the population relies on agriculture, rice being the staple food. Topography urges farmers to cultivate upland rice. The Chinese interest in rubber latex has stimulated farmers to grow rubber, although the technical knowledge regarding tree management and latex processing is poor. A study was conducted in an area in Luang Prabang province to examine the suitability of upland rice and rubber. The major objective was to make a comparison within and between three suitability evaluation methods, two of which are expert-driven whereas the third one was executed by a group of farmers. For the fuzzy model different membership values were set and weighed using the Analytic Hierarchy Process (AHP) technique. According to the Boolean classification 88% of the study area is suitable for upland rice, and 85% is suitable for rubber. The fuzzy method yielded 89% suitable for upland rice and 88% suitable for rubber. Farmers came up with 37% suitable for upland rice and 14% suitable for rubber. Comparison is made between the different methods. A reasonable agreement between farmers' suitability maps and the expert-based methods is obtained for the upland rice than for the rubber-based land utilization type (LUT). This can be attributed to the lack of know-how on the latter.

Key words: *ALES, Boolean Theory, Fuzzy Logic, Land Evaluation, Land Suitability*

1 INTRODUCTION

Land evaluation is the estimation of the possible behavior of the land (actual or potential) when used for a particular purpose (FAO, 1983). The FAO Framework for Land Evaluation (1976), which aims to determine land suitability for Land Utilization Types (LUTs) has been quite popular in the last decades (Verdoodt and van Ranst, 2003; FAO, 2007; Son *et al.,* 2008). FAO approach is based on matching land and LUTs, the latter being the produce (e.g., a given crop) plus the management (farm size, labor intensity, capital intensity, know-how, etc). While land is described in terms of land qualities (LQ) and land characteristics (LC), the needs of the LUT are expressed by land use requirements (LUR), which are not necessarily biophysical only. The land qualities are assessed using land characteristics, which are by definition measurable. Land use requirements are not always easy to determine and are often formulated using literature and/or expert knowledge, cross-checked with the site conditions. FAO methodology can be considered Boolean and discrete as continuous

* *Corresponding author: International Institute for Geo Information Science and Earth Observation (ITC), Enschede, the Netherlands. E-mail: farshad@itc.nl*

attribute values (e.g. elevation) are divided into many crisp partitions (e.g., from 0 to 100 meters, from 101 to 200 meters) and the interaction between land qualities and land characteristics is restricted to these discrete partitions (Xue *et al.,* 2007). The land evaluation assessment in Lao People's Democratic Republic (Lao PDR) has been done using Boolean classifications (see for example Nilsson and Svensson, 2006), assuming distinct classes and certainty in measurements and in their spatial distribution, while in reality soils and vegetation do not occur in discrete polygons (Hall *et al.,* 1992).

In contrast, fuzzy logic deals with continuous and imprecise environments (Zadeh, 1965). Contrary to the Boolean logic where a value is true or false (suitable or not suitable), in the fuzzy logic values may be partially false or partially true, and the partitions for continuous attributes are soft, i.e., intermediate values are allowed. Fuzzy classification has been proved useful for land suitability (e.g., Reshmidevi *et al.,* 2009; Xue *et al.,* 2007; Sicat *et al.,* 2005; Ceballos-Silva and López-Blanco, 2003; Nisar Ahamed *et al.,* 2000). Given the non-discrete character of soils and, to a large extent, of land use properties, fuzzy theory better suits the determination of land suitability. In other words, fuzzy theory facilitates intersections between any neighboring partitions (Xue *et al.,* 2007).

Regardless of the type of land evaluation performed, the organizations in charge of land use planning usually develop classifications without considering the farmers' opinion, which may result in suitability maps that do not agree with the interests or traditions of the farmers, who will implement them (FAO, 1997). On the other hand, farmers make their own classifications based on their experience, while considering the contemporary economy, land availability, and many other related issues. In their case, the lack of local knowledge will lead to wrong suitability estimations, and the difference of interests between farmers and their community can lead to misuse the land (Sicat *et al.,* 2005).

In this paper, two expert land evaluation methods, one Boolean-based and one fuzzy-based, using farmers' information as input, are applied to assess the suitability of upland rice and rubber-based LUT's in the Phonxay District in Lao PDR. The results are then compared to the suitability classification conducted by a group of local farmers.

2 STUDY AREA

Lao People's Democratic Republic (PDR) is a landlocked country of a total surface area of 236,800 km^2 with Thailand, Myanmar (Burma), China, Vietnam and Cambodia as neighboring countries (Figure 1). Around 70% of the country is mountainous. Elevation in the study area ranges between 350 and 1,512 meters but the maximum elevation used for agriculture is around 700 meters, due to the high slopes above this altitude (Figure 2). The lowest altitudes correspond to the valley of the river Nam Pa and its tributaries. The last land cover inventory in Lao PDR, conducted in 2002, shows that approximately 45% of the country is covered by forests making Lao PDR at that time one of the most heavily forested countries in SE Asia (UNCDF, 2002). Figure3A shows the current land use/cover in the study area obtained from the field survey. This study was carried out in a group of villages (*Kum Ban*) located in the District of Phonexay, in the Province of Luang Prabang, with a total area of 56.7 km^2. The total number of villages in the area is six, but administratively they have been categorized into four: Thapo (conformed by Thapotai and Thaponeua), Nam Bo, Houayman and Houaymaha (conformed by Houaymaha and Poungpao).

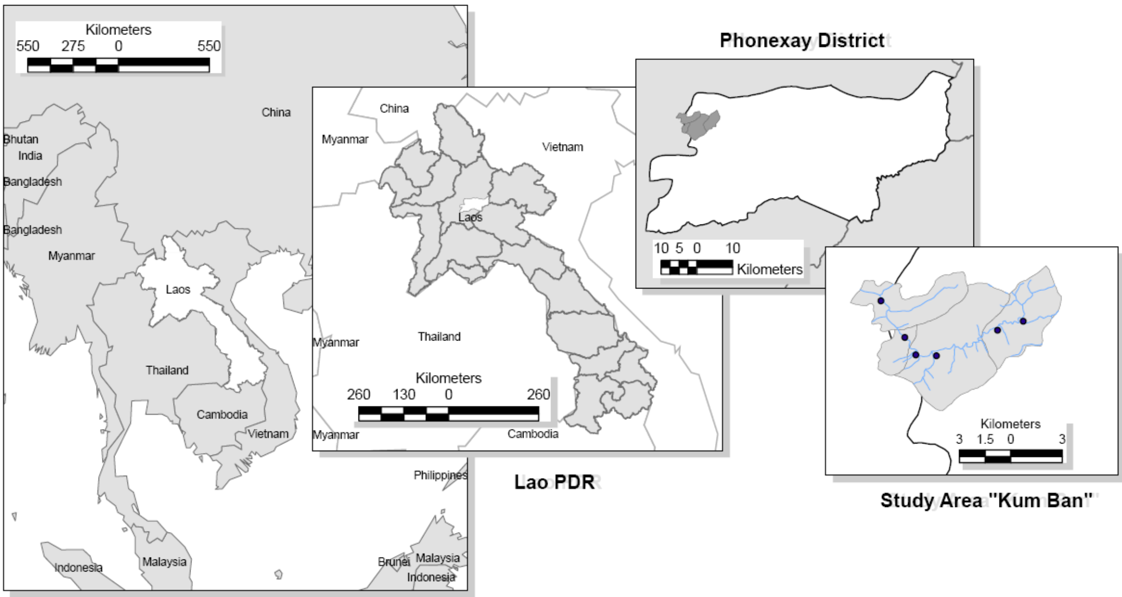

Figure 1 Geographical location of the study Area

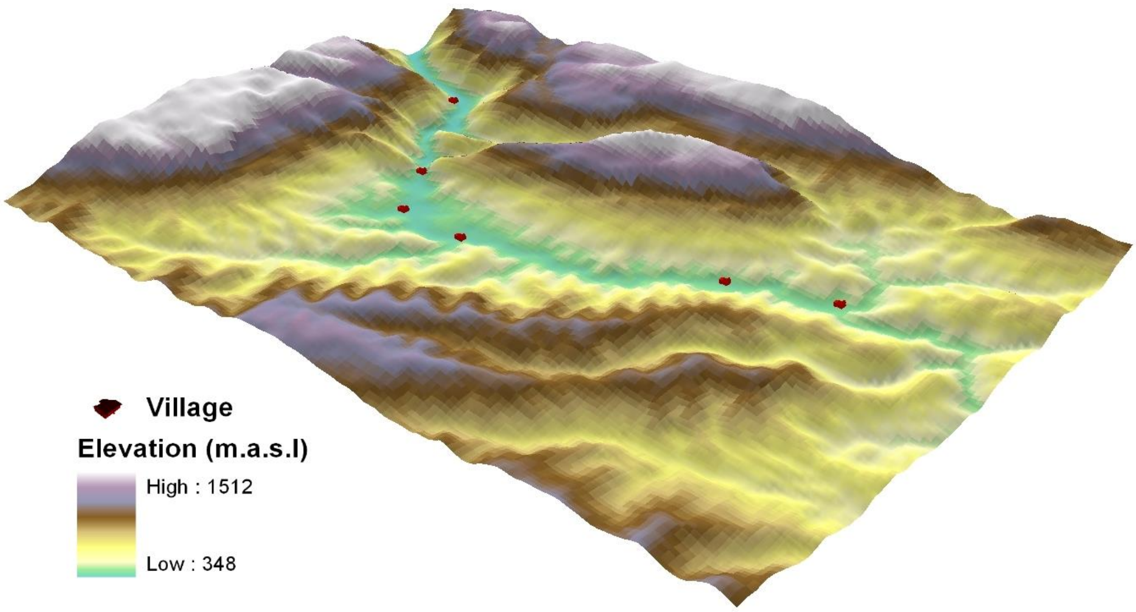

Figure 2 Topography of the study area (Source: USGS)

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Lao PDR is one of the least developed countries in the world (UNDP, 2004) with a Gross National Income (GNI) per capita of US$875 or less in 2005 (UNDP, 2008). High pressure on natural resources has resulted in the extensive deforestation and the introduction of new market-oriented crops (Mahanty *et al.*, 2006). Poverty is aggravated in the northern provinces due to the limited or lack of infrastructure, which restricts the access to markets and social services. Agriculture, which is the main source of subsistence for around 80% of the population, is restricted by the mountainous topography. Rice as the main staple food is cultivated in narrow valley floors and flooded areas, or as upland rice grown on steep slopes in a traditional way: without terraces, fertilizers, or use of machinery. Upland rice is harvested every six months. Rubber is planted along with other crops such as fruit trees or corn. It takes around 7 years before rubber trees can be tapped for latex ('Report on Rubber Suitability Zoning in the Central Development Zone, Na Mo District, Oudomsay Province', 2005). In the study area, rubber was introduced four years ago, meaning that no latex has been produced yet.

The Chinese market for rubber and sugar cane has stimulated farmers of Lao PDR to change the land use, moving from subsistence to cash and market-oriented crops, without having the required skills. To determine suitable areas, land development plans have been made based on conventional systems such as the Framework from Land Evaluation (FAO, 1976) and Agroecological zones guidelines (FAO, 1996). The main problem is that the land evaluations in the study area have been done for several crops, excluding rubber, using conventional Boolean classifications, relying mainly on the experience of soil scientists and with limited or without input from the farmers, leading to some outputs that do not necessarily reflect the desires and interests of the farmers.

The National Agriculture and Forestry Research Institute NAFRI, in their 'Report on Household Diagnostic Survey in Phonexay District' of 2004, identified the principal physiographic units in the study area as alluvial flood plains, valleys, undulating low terraces, undulating high terraces and rolling foot slopes and hills. The lithology belongs to argillite series, composed by mudstone, siltstone and fine-grained sandstone.

According to the 'Reports On Soil and Land Suitability' prepared by NAFRI in 2002, the soil map was prepared using the available data from the Soil Survey and Land Classification Centre (SSLCC) of Laos PDR, and on the basis of the Soil Map of the World (FAO *et al.*, 1988). The SSLCC produced the soil map for the Phonxay District using physiographic maps and aerial photographs along with fieldwork verification. Three soil groups can be distinguished in the area: Leptosols, Cambisols and Acrisols. The main soil units are Eutric Leptosols, Eutric Cambisols and Haplic Acrisols (Figure 3b).

The natural vegetation in the study area can be described as mixed deciduous forest, well correlated to soil types and water regime. It comprises moist and dry forests that occur mainly on undulating high terraces and rolling foot slope hills, respectively. The top canopy forests in the study area are composed by *Pterocarpus dalbergioides*, *Terminally pialata*, *Largerstroemia*, *Shorea robusta* among other species that can be found on undulating low to high terraces. The land use patterns in the study area can be broadly grouped as rain fed paddy rice, agricultural plantations, ray/shifting cultivations, forest plantations, temporarily unstocked forest and mixed deciduous forest. Upland rainfed rice and rubber fall into the agricultural plantations class.

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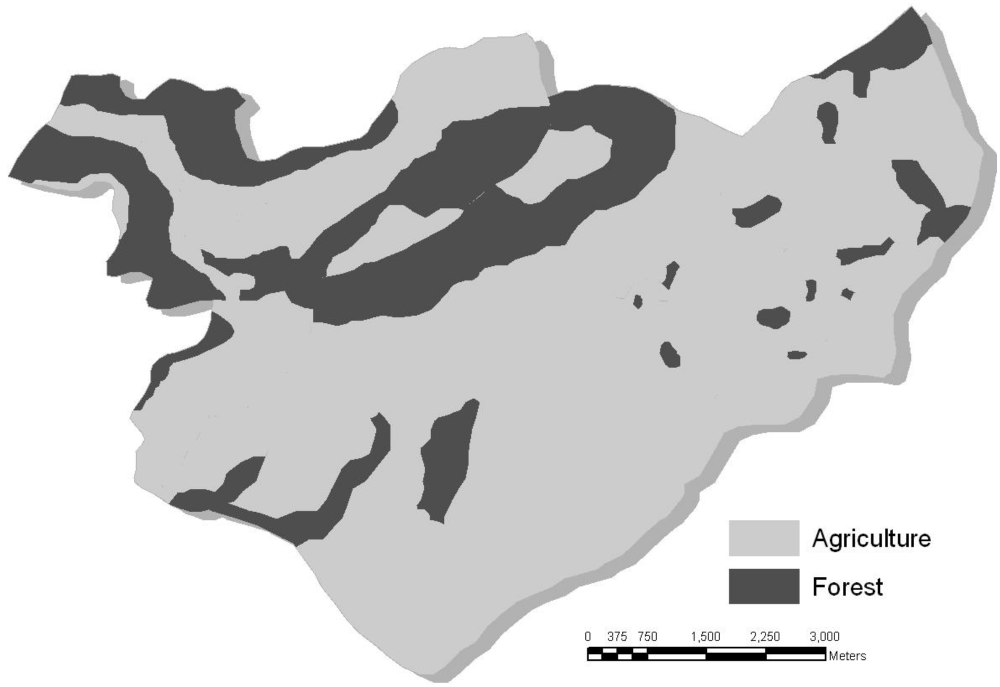

Figure 3a Land use/cover from field survey (2006)

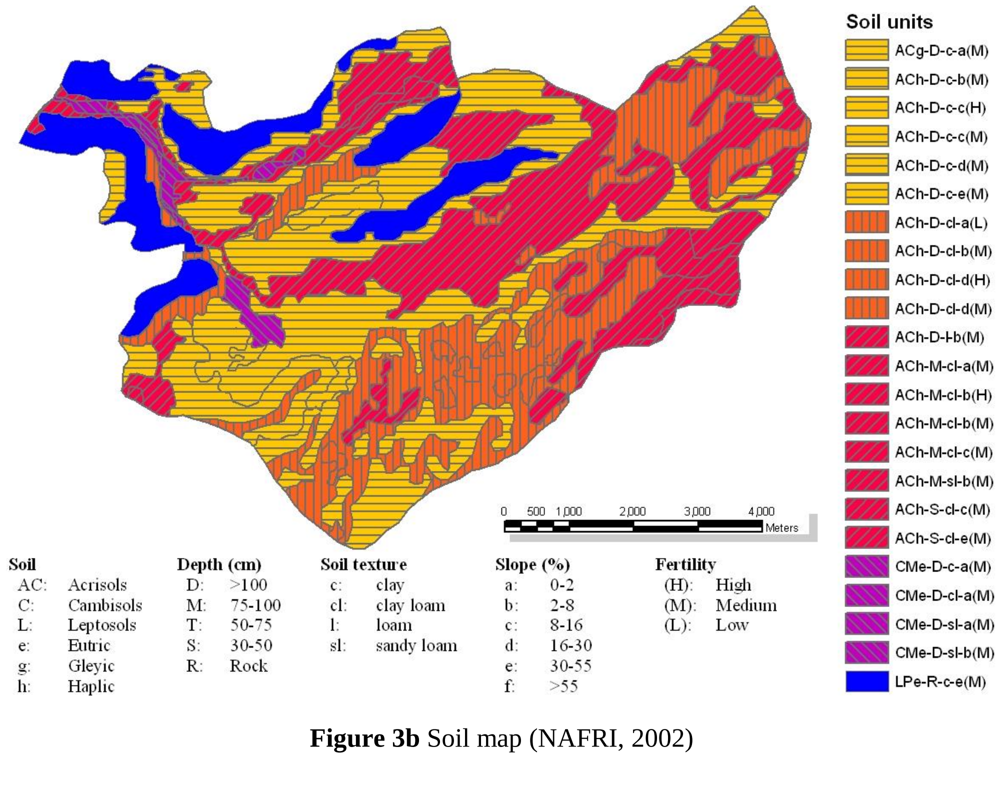

Figure 3b Soil map (NAFRI, 2002)

3 METHODS

The 'Reports On Soil and Land Suitability' state that the land units map, used as input for the land characteristics, was created based on the digital version of the soils map for the study area, in combination with aerial photographs scale 1:30000 from year 1991. The land characteristics maps were rasterized using 5x5m cells taking into account the small parcel size. Slope was derived from a DEM (Figure 2) with 90x90m resolution obtained from the USGS website (http://www.terrainmap.com/rm39.html). Given the extent of the study area (56.7 km^2), climatic condition is homogeneous, hence not included in the evaluations.

Once the land utilization types (LUT) were described using interviews and field verification (Table 1), a database including the land qualities, land characteristics, map units and decisions for suitability was constructed. Tables 2 and 3 present the land qualities and the diagnostic factors (land characteristics) for both land utilization types based on a conventional approach, that is to make use of expert knowledge, retrieved from literature and the authors experience, verified in the field. The fertility was defined using the same parameters employed in the 'Reports On Soils and Land Suitability'. These parameters are: percentage of organic matter (%OM), base saturation percentage (%BS), cation exchange capacity (CEC), available phosphorus, and available potassium (Table 4), determined at depths from 30 to 100 cm. For the Boolean and fuzzy classification, the same land qualities and land characteristics were considered for comparison purposes. Information derived from interviews, such as the relevance of workability and fallow period were introduced in both evaluations.

Table 1 Land Utilization types described

No.	LUT	Produce	Capital Intensity*	Labour Intensity Man-Months/Ha	Farm Power	Level of Technical Knowledge	Farm Size Ha/Household	Land Tenure	Incomes: Value Added**	Source
1	Rubber	Latex	Low	1	Manual	Traditional	2-4	Private	Low	NAFRI and Interviews
2	Upland Rainfed Rice	Upland Rice	Low	1	Manual	Traditional	2-4	Private	Low	Interviews

*Capital intensity (U$/ha): Low: 500-700; Medium: 700-1000; High: >1000
**Income (approx. U$/ha): Low: 600-900; Medium: 900-2000; High: >2000

Table 2 Land qualities and land characteristics for upland rice

LAND QUALITY	LAND CHARACTERISTIC	UNITS	SUITABILITY CLASSES s1	s2	s3	n
Soil fertility	Fertility	Class	High	Medium	Low	None
	Fallow period*	Class	Old	Medium	Young	No fallow
Moisture availability	Soil texture (USDA)	Class	cl, sc, c	s	sl	c (heavy)**
	Soil depth	cm	30-200	20-30	10-20	0-10
Rooting conditions	Soil depth	cm	50-300	30-50	-	0-30
Erosion hazard	Slope	%	0-20	20-50	50-100	100-200
	Observed erosion		None	Low	Moderate	High
Workability	Slope	%	0-10	10-20	20-50	50-200
	Soil texture (USDA)	Class	sc, sl	cl, l	c	Rock
	Fallow period	Year	0-1	1-2	2-4	4-7
	Soil depth	cm	75-300	50-75	30-50	0-30
Accessibility	Slope	%	0-20	10-50	50-100	100-200
	Proximity to villages	m	0-500	500-1000	1000-2000	2000-5000

*Old fallow: 4-7 years. Medium: 2-4 years. Young: 1-2 years. No fallow: 0-1 year
**Compact or dense clay.

Table 3 Land qualities and land characteristics for rubber

LAND QUALITY	LAND CHARACTERISTIC	UNITS	SUITABILITY CLASSES s1	s2	s3	n
Soil fertility	Fertility	Class	High	Medium	Low	None
	Fallow	Class	Old	Medium	Young	No fallow
Moisture availability	Soil texture (USDA)	Class	cl, sc	l	sl	c (heavy)*
	Soil depth	cm	100-500	50-100	30-50	0-30
Rooting conditions	Soil depth	cm	100-500	70-100	50-70	0-50
Erosion hazard	Slope	%	0-20	20-50	50-100	100-200
	Observed erosion	Class	None	Low	Moderate	High
Workability	Slope	%	0-10	10-20	20-50	50-200
	Soil texture (USDA)	Class	sl, cl, l, c	-	-	-
	Fallow	Year	0-1	1-2	2-4, 4-7	-
	Soil depth	cm	-	-	-	0-30**
Accessibility	Slope	%	0-20	10-20	20-40	40-200
	Proximity to villages	m	0-500	500-1000	1000-2000	2000-5000

*Compact or dense clay
**Rubber requires a minimum depth of 30cm

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Table 4 Criteria for fertility evaluation

Criteria	Organic Matter (%OM)	Base Saturation (%BS)	Total of Cation Exchange Capacity (CEC-Tme/100g of soil)	Available Phosphorus (P_{-PPM}) (BRAY-II method)	Available Potassium (K_2O mg/100g of soil)	pH
Low	<2.0	<50	<10	<10	<4.0	<3.5 or >7.8
(Rate)	(1)	(1)	(1)	(1)	(1)	(1)
Medium (M)	2.0-4.0	50-75	10-20	10-25	4.0-12.0	4.0-5.0
(Rate)	(2)	(2)	(2)	(2)	(2)	(2)
High (H)	>4.0	>75	>20	>25	>12.0	5.0-7.8
(Rate)	(3)	(3)	(3)	(3)	(3)	(3)

3.1 Conventional Knowledge-Based Model (Boolean)

The Boolean expert-based classification was done using the Automated Land Evaluation System (ALES) v. 4.65 (Rossiter and Wambeke, 1997), choosing for the maximum limitation option (Sys *et al.*, 1991) through defining decision trees where the interaction of the land qualities and land characteristics is established. In ALES the final suitability is the result of the comparison between matrices that relate the inputs given for each land unit against the limiting factors for the land utilization types.

For the Boolean classification, to evaluate fertility at locations where data on cation exchange capacity and base saturation are not available, NAFRI has used pH combined with phosphorus and potassium. NAFRI assigns rates to the parameters influencing fertility which are qualification values from 1 to 3, being 3 a high rate. The index that determines the overall fertility is obtained adding up the different rates. An index equal or below 7 indicates low fertility (L), between 8 and 12 medium fertility (M) and equal or above 13 a high fertility (H) (Table 4). These categories for fertility were assigned to the LUTs for the suitability evaluation.

3.2 Fuzzy-Based Model

The process to obtain the land suitability evaluation based on fuzzy logic is summarized in Figure 4. Zadeh (1965) defined a fuzzy set as “a class of objects with a continuum of grades of memberships”; where a membership is a function that assigns to each object a grade ranging between zero and one. The membership grades indicate the extent to which the entities belong to a class (Hall *et al.*, 1992).

McBratney and Odeh (1997) expressed the fuzzy membership function as $\mu A(x) \in [0,1]$ with each element x belonging to X with a grade of membership $\mu A(x) \in [0,1]$. In this way $\mu A(x) = 0$ represents that the value of x does not belong to A and $\mu A(x)=1$ means that the value belongs completely to A. Alternatively $0 < \mu A(x) < 1$ implies that x belongs in a certain degree to A. The memberships for a fuzzy classification of suitability are given between 0 and 1, being 1 a highly suitable area and 0 a not suitable one.

The relative importance of the suitability of each factor in relation to the rest of the factors contributing to the suitability was represented by weights. The weights are experience-based, statistically analyzed or obtained through an Analytic Hierarchy Process (AHP) (Saaty, 1980). The latter, a combination of experience

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and a mathematical process, was chosen due to its relative simplicity and because it allows assigning different levels of importance to the parameters involved in land suitability testing.

The AHP is a method that facilitates the selection of weighting criteria and admits the decision making when there are a limited number of choices, each choice with attributes that are difficult to formalize. AHP relies on pair-wise comparison matrices (PCM) which are matrices relating different components and assigning values according to their relative importance. These values are given by a scale from 1 to 9, where 1 means that the two elements being compared have the same importance and 9 indicates that from the two elements one is extremely more important than the other (Saaty and Vargas, 2001).

The relative importance was assigned to the different parameters comprising the land suitability evaluation based on experience. Fertility was estimated using the same parameters given in Table 4. As an example Table 5 shows the PCM for the land characteristic ‘fertility’: organic matter was considered more important than available potassium due to its relevance for yield production, therefore it received a value of 5 when compared to potassium, while potassium when compared to organic matter received its reciprocal, 1/5. The final weight is the result of dividing each record value by the sum of the respective column and then calculating the average for the corresponding row.

Table 5 Pair-wise comparison matrix to determine the weighting factors of the land characteristics that evaluate the land quality ‘soil fertility’

Elements	Cation Exchange Capacity	Organic Matter	Base Saturation	Available Phosphorus	Available Potassium	Weight
Cation exchange capacity	1	4	3	7	7	0.463
Organic matter	1/4	1	1/5	5	5	0.144
Base Saturation	1/3	5	1	6	6	0.298
Available Phosphorus	1/7	1/5	1/6	1	1	0.047
Available Potassium	1/7	1/5	1/6	1	1	0.047

Table 6 Pair-wise comparison matrix to determine the weighting factors of the land characteristics that evaluate the land quality ‘workability’ for rice

	Slope	Texture	Fallow	Depth	Average
Slope	1	1/2	1/3	2	0.182
Texture	2	1	2	2	0.379
Fallow	3	1/2	1	2	0.302
Depth	1/2	1/2	1/2	1	0.138

The relative importance of the different land qualities relevant for rubber and upland rice suitability have been determined based on the land characteristics. First, the importance of each land characteristic within a land quality was estimated (rice workability, Table 6). Then the importance of each land quality compared to the other land qualities was established (Table 7 for rubber). The final weight of a land characteristic is the product between its partial weight within the land quality and the overall land quality weight. When a land characteristic appeared in more than one land quality, e.g. slope or depth, the final weight of this land characteristic is the sum of the partial weights within different land qualities.

To obtain the fuzzy maps for land suitability the convex combination of the raster values containing the different fuzzy parameters was calculated. The convex combination means that "if $A_1,\ldots A_k$ are fuzzy subclasses of the defined universe of objects X and $w_1,\ldots w_k$ are non-negative weights summing up to unity, then the convex combination of $A_1,\ldots A_k$ is a fuzzy class A whose membership function is the weighted sum" (Burrough, 1989), where the weights $w_1,\ldots w_k$ were calculated using APH and the fuzzy parameters μ_I have been calculated with the membership functions described below and using conditional statements in ArcGIS. Equations 1 to 3 present the convex combination defined by Burrough:

$$\mu_A = w_1 \cdot \mu_{A1} + \ldots\ldots w_k \cdot \mu_{A1} \quad (1)$$

$$\mu_A = \sum_{j=1}^{k} w_j \cdot \mu_{Aj}(x) \quad \text{with } X \in x \quad (2)$$

where:

$$\sum_{j=1}^{k} w_j = 1 \qquad w_j > 0 \quad (3)$$

For each soil parameter a membership function or probability weight was used to create the respective fuzzy parameter. The membership functions were obtained from literature. As an example, the fuzzy fertility is the combination of the parameters used for its evaluation (Table 4) where each parameter has been fuzzified using a membership function. The fuzzy land characteristics were combined for each land quality using weights obtained from the AHP (e.g. Table 6). Afterwards the fuzzy land qualities were combined using their weights (Table 7 for rubber). Unlike the Boolean methodology, pH was not a parameter considered by the membership functions to evaluate fertility, therefore two land units (0.90 km^2, equivalent to 1.6% of the total study area) remained without fertility values and were not evaluated with the fuzzy method.

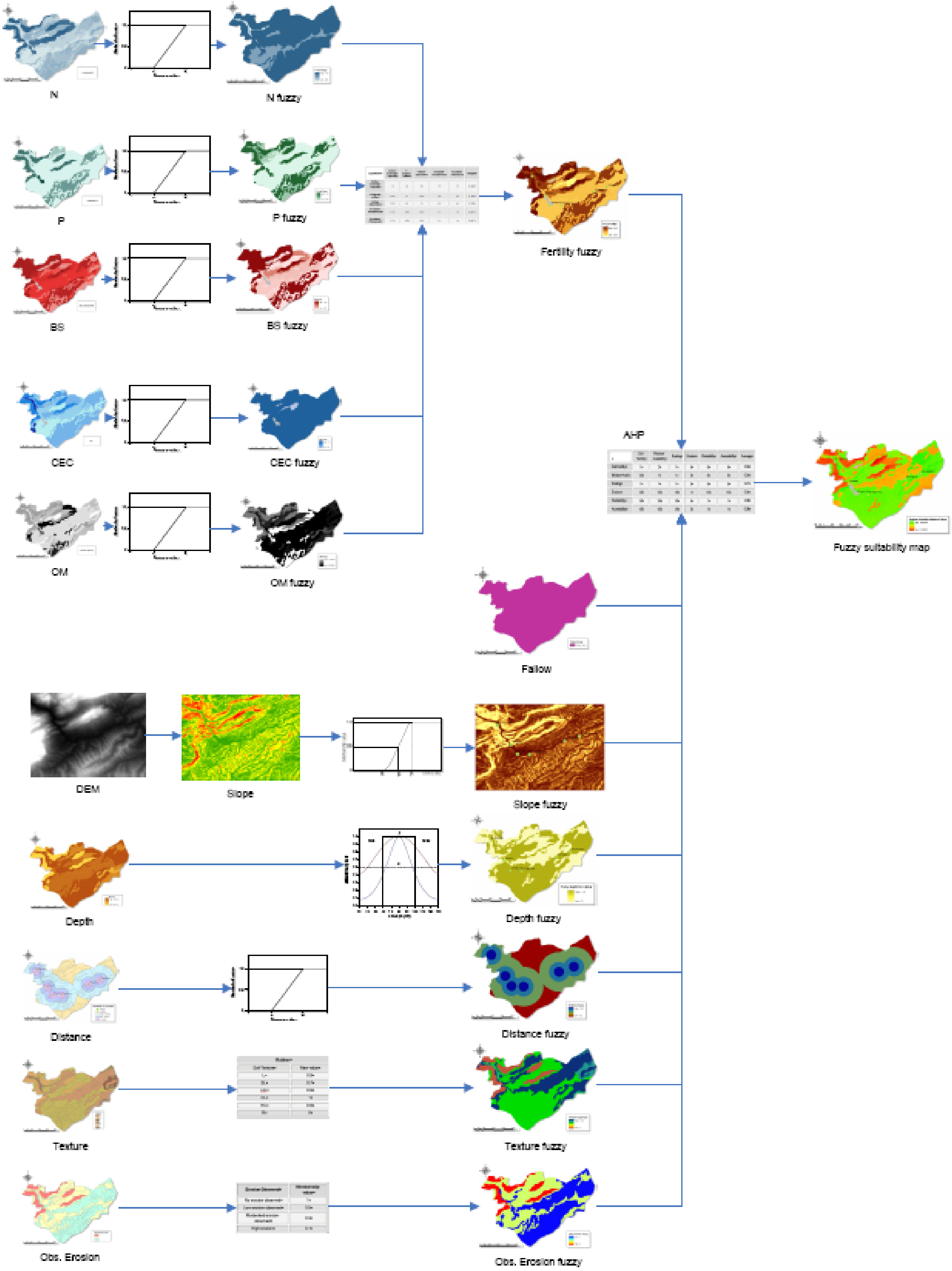

Figure 4 Fuzzy process for land suitability

The membership calculation was done using a linear function for fertility and distance (Equation 4), a second grade function for soil depth (Equation 5 and Figure 5) and an *S* membership function for slope (Equation 6).

$$\mu A(x) = \begin{cases} 0 & x \le a \\ \frac{x-a}{b-a} & a < x < b \\ 1 & x \ge b \end{cases} \qquad X \in x \quad (4)$$

In Equation 4, *x* is the input data and, *a* and *b* are the limit values established according to Tables 2 and 3. This function has been used considering a proportional and linear increment of fertility with the increase of each factor, also employed by Schubert (2004) for Sri Lanka with satisfactory results.

$$\mu A(x) = \begin{cases} \frac{1}{1 + a \cdot (x-c)^2} & x < c \\ 1 & x \ge c \end{cases} \qquad X \in x \quad (5)$$

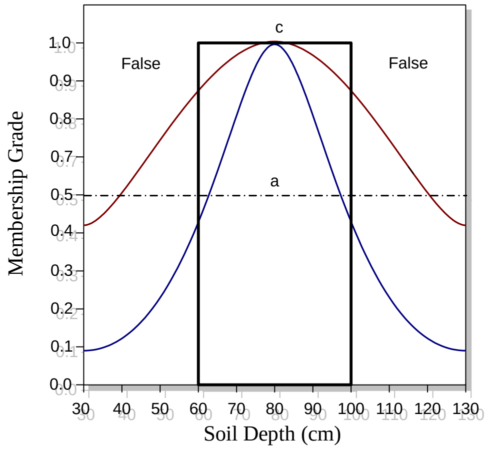

Figure 5 Membership function for asymmetrical second grade function (adapted from Burrough, 1989)

In the equation 5, tested for soil depth (Burrough, 1989), *a* is a parameter that controls the shape of the function and the position of the cross-over points; the expression $(x\text{-}c)^2$ controls the dispersion. The limits given in Equation 5 are equivalent of an S membership function, which according to Burrough (1996) produces better results compared to other membership functions for soil science parameters.

For slope, an S membership function (Figure 6) as defined by Tang *et al.* (1991) was used. The limits *a* and *b* correspond to the limit conditions of steep slopes and flat terrain respectively.

$$S(x;\alpha,\beta,\gamma) = \begin{cases} 0; & x \in \left]-\infty,\alpha\right[\\ 2[(x-\alpha)/(\gamma-\alpha)]^2; & x \in [\alpha,\beta[\\ 1-2[(x-\gamma)/(\gamma-\alpha)]^2; & x \in [\beta,\gamma[\\ 1; & x \in [\gamma,+\infty[\end{cases} \qquad (6)$$

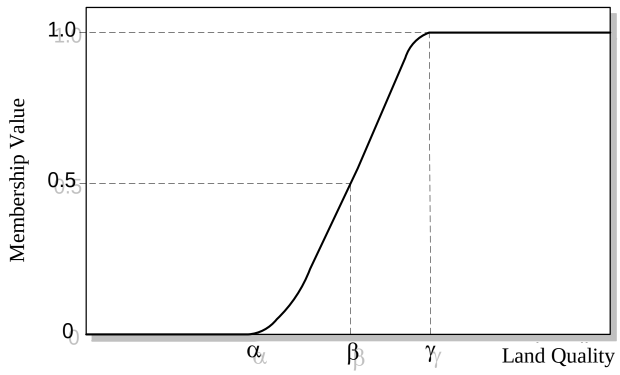

Figure 6 S membership function (adapted from Tang *et al.*, 1991)

3.3 Farmers' Suitability Maps

To create maps that represent the farmers' perception of the soils and their potential use

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"group discussions" with household representatives of the four administrative villages were carried out. In these meetings a topographic map (scale 1:25000) and a satellite image (ASTER, 1:25000, from November 2000) were used as reference for the farmers. First, the farmers identified the main rivers and topographic features; afterwards, they delineated on a tracing paper the soils distribution of the area. Farmers' soil classification in the study area is based on color and texture combination (Douangsavanh *et al.,* 2006) and in some cases by stoniness and/or rockiness. To produce suitability maps according to the farmers' perception, once the soil map for the whole village was produced the farmers were inquired about the potential use of the soil units they identified. For suitability evaluation, besides the soil type, farmers take into account the number of years that the plots have been under fallow, which is variable across the study area and, according to the farmers, determines the number of times the soil can be cultivated. After the soil classification was done, a meeting with members of each village was held and interviews regarding land management, tenure, cultivation techniques, income, labor intensity, farm size, and accessibility were carried out. In each village between 6 and 8 farmers were interviewed independently. To corroborate and complement the answers given during the interview, additional open questions were posed to all the participants of the meetings. The format for the interviews was originally prepared in English and translated into Lao by personnel of NAFRI. The results of the interviews were tabulated, summarized and employed to describe the LUTs and land characteristics used in the suitability evaluation (Tables 1 to 3).

3.4 Maps Comparison

The resulting maps from ALES (Boolean evaluation), fuzzy modeling and the farmers' perception were compared on a cell by cell basis. To perform the comparisons, the fuzzy suitability maps were reclassified into 4 classes (judged to correspond with the four suitability classes) using the natural breaks from the histogram, where the classes are assigned according to the gaps between clusters of similar values. To determine the conformity between the raster maps they were combined based on their class number. Values such as 11, 22, 33 and 44 represent class correspondence between cell values from two maps. For the farmers, fallow is a determinant factor for suitability, but the plots in the study area are under different fallow periods, a difficult issue as fallowing is judgment-oriented rather than being solely attributable to soil (as shown in the soils map, Figure 3b) or climatic condition, or anything which follows a regular pattern. To represent the influence of fallow in the suitability assessment four fallow periods (as scenarios) were considered (no fallow, young, medium and old). The land suitability results for each fallow period were compared both for rice and rubber. Three maps were obtained for each suitability assessment for rubber, and three for upland rice, considering three fallow periods (the map results from no fallow and young fallow were equivalent). Similarity matrices were made to compare the three types of land evaluation for each of the fallow periods. In this paper only the matrix for the comparison between Boolean and fuzzy evaluation for rubber during the medium fallow period is presented (Table 11). To assess the agreement between two maps, the kappa statistic (Cohen, 1960) was calculated. A kappa value of 0 indicates that there is no agreement between the maps, in other words, they are not related. A value of 1 indicates a perfect agreement; a value between 0 and higher than -1 indicates that the agreement is expected to be by chance while a value of -1 or lower represents complete disagreement (Rossiter, 2004). For the

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comparison with the farmers' suitability maps, areas classified as suitable by the farmers (value 1) have been compared to the three suitability classes (S1, S2 and S3) as an aggregated class 1, while the other areas (value 0 in farmers' class) were compared to the not suitable areas (N) as a class 0. In Table 12, the areal difference represents the proportion of overestimation or underestimation of a class in one map respect to the same class in the other map. The fuzzy agreement (Table 11) and Boolean agreement (Table 12) represent the percentage of agreement of one map versus the other, while the mean agreement (Table 12) is a combination of both fuzzy and Boolean agreement. N is the total number of cells, the parameter d represents correctly classified cells and the parameter q is the sum of the products between correctly classified cells and the total number of cells for each class; these two parameters are used to calculate the kappa statistic per class (Table 12) and for the whole classification (Table 13). The overall agreement indicates the general correspondence between the two maps as a whole and is obtained dividing the correctly classified cells between the total number of cells classified (Table 13).

4 RESULTS

4.1 Boolean-Based Land Suitability

Figure 7 presents the results of the Boolean suitability evaluation. In the Boolean method, fallow is a determinant land characteristic, that affects the fertility and the workability but it is difficult to quantify. Slope is another important land characteristic that influences workability, accessibility and the erosion hazard. For all the different types of fallow period considered, 12% (680 ha) of the total study area is not suitable for upland rice cultivation; 88% of the total study area (4,990 ha), is somehow suitable for upland rice. The percentage of area moderately suitable for upland rice varies, being 61%, 49% and 48% of the total area for no fallow, medium fallow and old fallow, respectively (Table 8). 85% of the study area (4,820 ha) is somehow suitable for rubber. Fallow period decreases the suitability for upland rice due to workability: a plot with a long fallow implies more work on slashing and weeding. According to the Boolean-based classification, the optimal condition for upland rice is 'no fallow' (0 to 1 year). Workability is a constraint for rice suitability, and land without fallow implies less weeding and slashing but with just enough nutrients in the soil. For rubber, the best condition is medium fallow (2 to 4 years) with 21% of the study area (1,191 ha) being highly suitable (Table 9). During this period of time the soil nutrients will be replenished and hence a better yield can be expected.

4.2 Fuzzy-Based Land Suitability

With the fuzzy approach it is possible to find highly suitable areas both for upland rice and rubber with membership values between 0.88 and 0.91 for upland rice and between 0.95 and 0.97 for rubber.

After reclassifying the suitability values based on natural breaks of the raster histogram, four defined classes were obtained, judged to correspond to the four suitability classes S1, S2, S3 and N. The reclassified values for the fuzzy model are shown in Figure 8. The fuzzy based classification shows that 88% of the total study area falls within a certain suitability class, both for rice and rubber, which is about the same area as in the Boolean classification (Tables 8 and 9). From the total area, 50% (2,835 ha) is highly suitable (S1) for upland rice, for a medium fallow period. In the case of rubber the total area suitable is 88% as well, but only 24% (1,360) is highly suitable. Fallow period is a land characteristic difficult to quantify but relevant for workability and fertility. Fallow is more significant for rice than for rubber because fertility is the most important parameter for rice, while for rubber workability and fertility are less relevant than moisture availability. Fertility was a problematic land characteristic: for the Boolean model a category of fertility is available for every land unit (high, low, medium), but the fuzzy model requires numeric values that were not available for two land units that remained without data. Tables 8 and 9 summarize the results of suitability for different fallow periods and for the Boolean and fuzzy models.

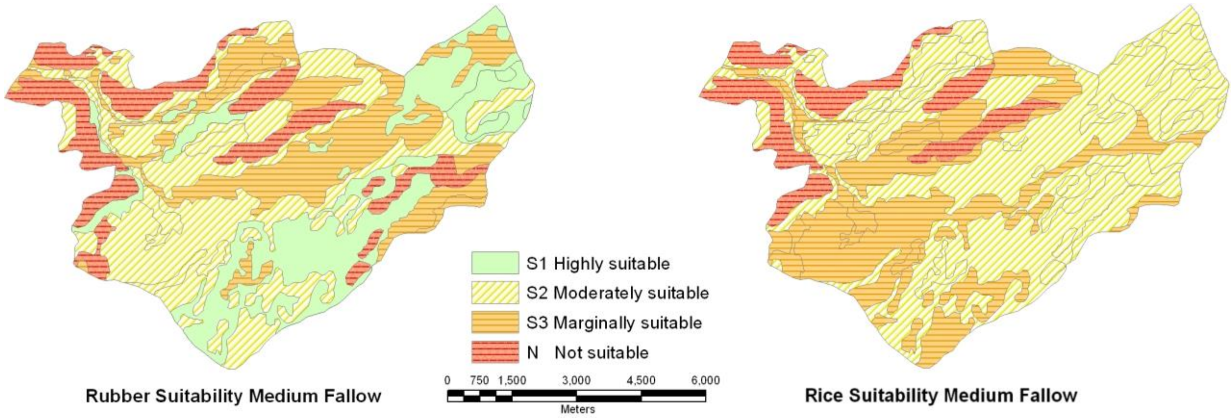

Figure 7 Land suitability results based on Boolean model for rubber (left) and rice (right) during medium fallow period

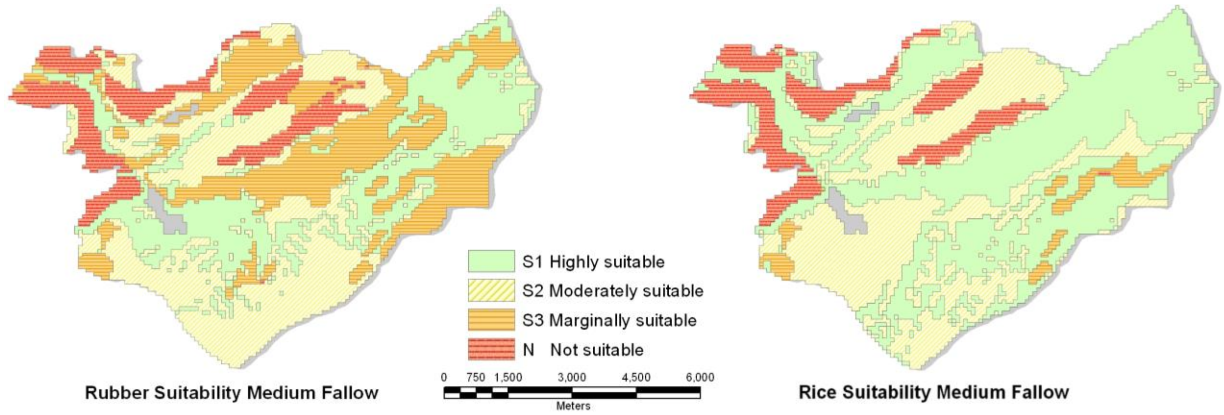

Figure 8 Land suitability results based on Fuzzy theory for rice (left) and rubber (right) during medium fallow period

Table 7 Pair-wise comparison matrix to determine the weighting factors for the land qualities that evaluate rubber suitability

[DOR: 20.1001.1.23222700.2013.1.3.7.1]

	Soil Fertility	Moisture Availability	Rooting	Erosion	Workability	Accessibility	Average
Soil Fertility	1	1/2	1/5	5	1	1	0.11
Moisture Avail.	2	1	1	5	5	5	0.28
Rooting	5	1	1	5	5	5	0.34
Erosion	1/5	1/5	1/5	1	1/5	1/5	0.04
Workability	1/5	1/5	1/5	5	1	5	0.12
Accessibility	1/5	1/5	1/5	5	5	1	0.12

Table 8 Areal extent of the Boolean and fuzzy land suitability classification tools for upland rice

Fallow Period	No Fallow				Medium Fallow				Old Fallow			
Suitability	Boolean		Fuzzy		Boolean		Fuzzy		Boolean		Fuzzy	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Highly Suitable (S1)	0	0	2778.3	49	0	0	2835	50	0.0	0	2778.3	49
Moderately Suitable (S2)	3458.7	61	2041.2	36	2778.3	49	2041.2	36	2721.6	48	2041.2	36
Marginally Suitable (S3)	1530.9	27	170.1	3	2211.3	39	170.1	3	2268.0	40	170.1	3
Not Suitable (N)	680.4	12	680.4	12	680.4	12	623.7	11	680.4	12	680.4	12

4.3 Farmers' Soils And Suitability Map

Figure 7 shows the suitable areas for upland rice and rubber according to the farmers' perception. Areas in dark were classified as suitable for other types of uses, where the farmers prefer traditional cash and subsistence crops such as soybean, teak, and sesame, among others, or where the land is under forest. The interviews show that cultivating rice is not something new. Farmers are quite experienced in rice cultivation (the knowledge is transmitted from one generation to the other), whereas there is a lack of know-how in rubber plantation. From the interviews it also became known that farmers, who have started planting rubber, rely on the information provided by relatives or friends who are cultivating rubber in other areas. It is remarkable that many farmers plant rubber not on their own initiative, but are supported by one or another organization such as the Swedish International Development Cooperation Agency SIDA. No yield was produced in the time of this study, when the oldest trees were around four years old. The lack of experience on rubber may result as well in the wrong selection of rubber species for the area and possibly difficulties in harvesting, as stated by NAFRI in the 'Report on Rubber Suitability Zoning in the Central Development Zone' from 2005. Table 10 presents the surface areas (in ha) that are suitable according to the farmers. Detailed results can be found in Sanchez-Moreno (2007).

[DOR: 20.1001.1.23222700.2013.1.3.7.1]

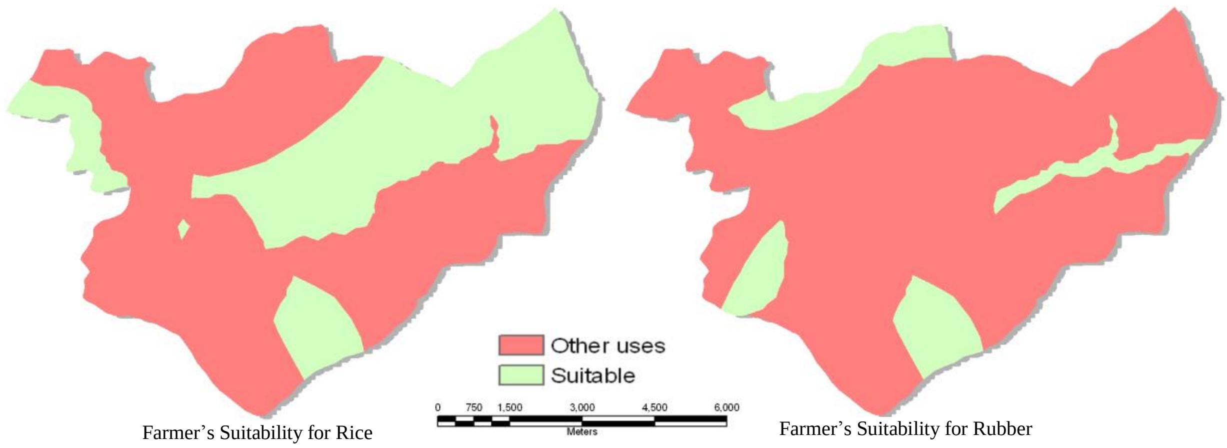

Figure 9 Farmer's suitability for upland rice (left) and rubber (right)

Table 9 Areal extent of the Boolean and fuzzy land suitability classification tools for rubber

Fallow Period	**No Fallow**				**Medium Fallow**				**Old Fallow**			
Suitability	**Boolean**		**Fuzzy**		**Boolean**		**Fuzzy**		**Boolean**		**Fuzzy**	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Highly Suitable (S1)	17.0	0.3	1360.8	24	1190.7	21	1360.8	24	0.0	0	1360.8	24
Moderately Suitable (S2)	2194.3	38.7	2097.9	37	1134	20	2097.9	37	2324.7	41	2097.9	37
Marginally Suitable (S3)	2596.9	45.8	1530.9	27	2494.8	44	1530.9	27	2494.8	44	1530.9	27
Not Suitable (N)	861.8	15.2	680.4	12	850.5	15	680.4	12	850.5	15	680.4	12

Table 10 Areal extent of the farmer's suitability classes for Upland Rice and Rubber

	Upland Rice		Rubber	
	Area	**%**	**Area**	**%**
Suitable	2098	37	794	14
Not defined	3572	63	4876	86

5 COMPARISON OF LAND SUITABILITY MAPS

5.1 Agreement Maps

Regarding the problematic issue of the different fallow periods, the medium fallow was decided to be considered a theoretical average situation for the study area. The suitable classes obtained from the Boolean and fuzzy methods (S1, S2, S3) were pooled together to form a single suitable class in order to compare the results with the farmers suitability class.

5.1.1 Boolean And Fuzzy Suitability Evaluation

Tables 11 to 13 present, as an example, the similarity matrices and areal agreement after comparing Boolean and fuzzy classifications for rubber during a medium fallow period. Table 14 shows the summary of the comparison results for rice and rubber under different fallow periods. The comparison of the Boolean and fuzzy suitability maps for upland rice shows that the best overall agreement of 31.8%, with a kappa of 10% was for no-fallow (Table 14). This result is due, among other reasons, to the lack of highly suitable areas (S1) in the Boolean map. For both LUTs the best agreement between the experts' classifications was found for not-suitable areas, indicating rockiness limitation to suitability in both assessments (Figures 5 and 6). The results for medium fallow and old fallow show an overall agreement of 18.4% and 18.3% respectively, with very low kappa values, of -2.5% and -2.3% (Table 14).

For rubber, the kappa values for the suitability classes' comparisons show that not-suitable areas (N) highly agree for both classifications (kappa 88.93%, Table 12) when compared to the suitable classes. In the same way, the areal difference (over estimation or under estimation of an area) for not-suitable areas is low, indicating high correspondence (Table 12). For the other suitability classes the differences are high, particularly for S2 where the areal difference is 81.5% (only 18.5% coincide) indicating that there was low correspondence between the areas classified as moderately suitable. The overall agreement obtained for the fuzzy map when compared to the Boolean map is 54%, with a kappa statistic of 38.3% (Table 14). The results show that the Boolean model for rubber comes up with less moderately suitable areas than the fuzzy model.

The assessment of the Boolean and fuzzy maps for rubber presents better results than the comparison made for rice: the kappa values are higher (31% for S1, 71.5% for S3, 89% for N) with the exception of S2, moderately suitable (8.2%, Table 12). On the other hand, the areal differences are quite large, more area has been assigned to S1 and S3 from the fuzzy model in relation to the Boolean model; while for S2 there is an underestimation of the area. In general these results show that there is no high coincidence between the three suitable classes, even though the percentage of area classified as suitable is the same and corresponds in both methods. This can be attributed to the restrictions caused by the maximum limiting factor method to the suitability classes, which is particularly reflected in the land characteristic 'fallow'.

5.1.2 Boolean And Farmers Suitability

For upland rice, the overall correspondence between suitable areas, obtained from the Boolean and the farmer's classification is 35.4% for the different fallow periods, with a very low and negative kappa of -3% (Table 14). For upland rice under the Boolean model highly suitable plots were not found, hence the correspondence of suitability with the farmers' results had to be compared with the other suitability levels (S2 and S3) as a single suitable class. From the classification made by the farmers, 86% of the plots defined as suitable falls within a suitable area (S2 or S3), of which 60% corresponds to the moderately suitable areas (S2). For rubber the classification made by the farmers has an overall agreement of 24% for no-fallow period and old-fallow period, and an overall agreement of 22% for medium fallow.

From the total area classified by the farmers as suitable for upland rice, 14% falls within not suitable areas according to the Boolean model which is equivalent to 290 ha; in the same way, 15% of the area classified by the farmers as suitable for rubber, equivalent to 120 ha, falls into not-suitable (N) areas.

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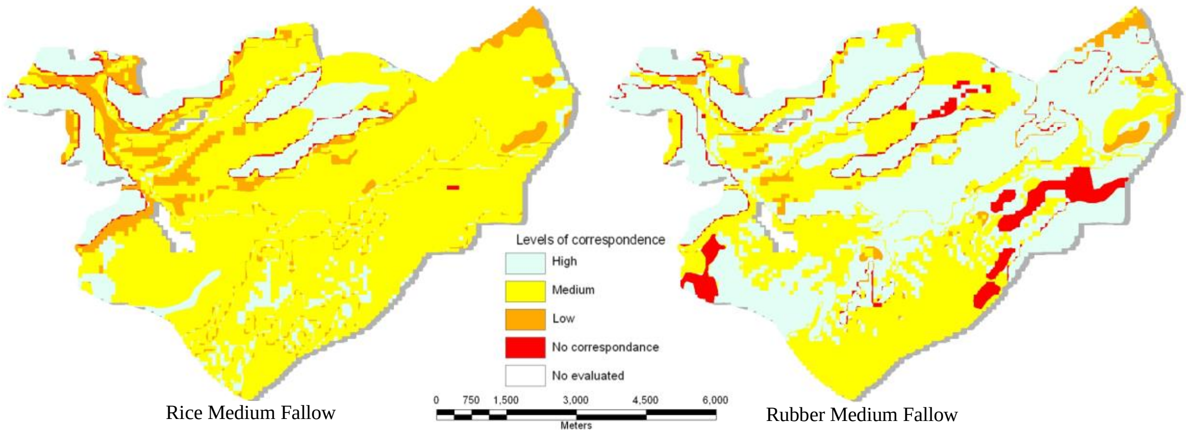

Figure 10 Similarity maps between Boolean and fuzzy theory for medium fallow period

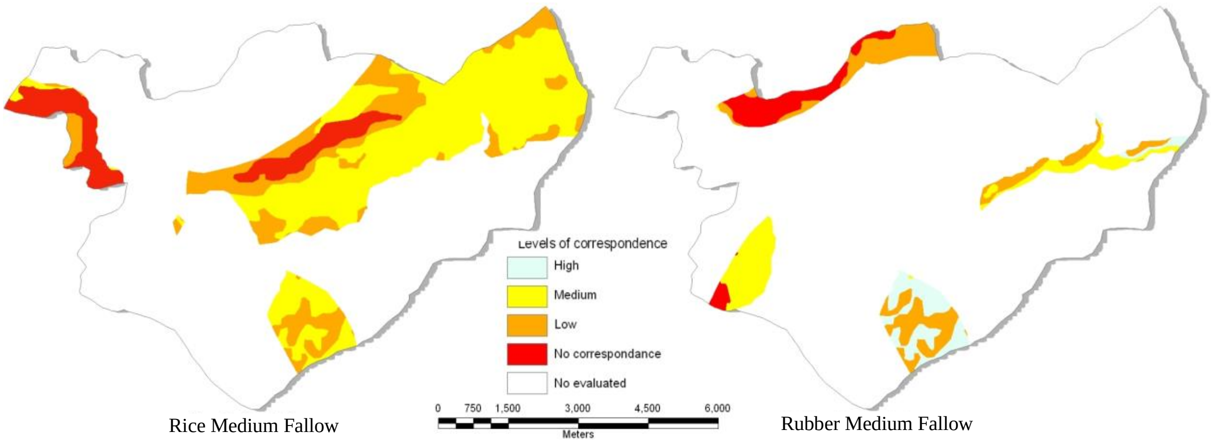

Figure 11 Similarity maps between farmers and Boolean theory for upland rice (left) and rubber (right) medium fallow period

5.1.3 Farmers and Fuzzy Suitability

The summary of the comparison results is presented in Table 14. The comparison between fuzzy-based suitable areas (S1, S2, S3) and the farmers' suitable class (single class 1) produced an overall agreement of 21.7% for rubber with a low kappa of -10%, and of 38% for upland rice with a kappa of -30%, for the different fallow periods. From the total area classified by the farmers as suitable for upland rice, 42% corresponds with the suitable areas (S1, S2, S3) obtained from the fuzzy classification. The kappa statistic remains low, 23% for the class 1 and 5% for the whole classification.

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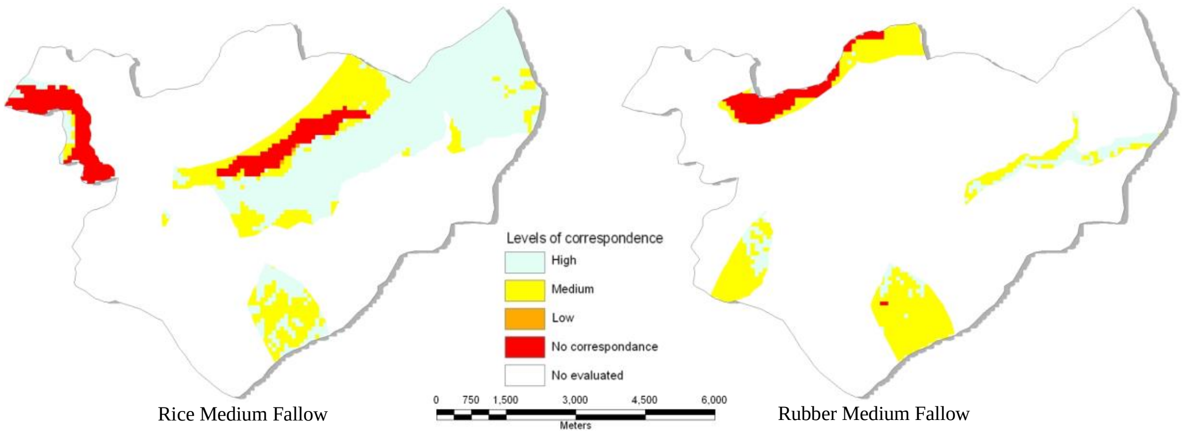

Figure 12 Similarity maps between farmers and Fuzzy theory for upland rice (left) and rubber (right) during medium fallow period

Table 11 Similarity matrix and accuracy of fuzzy map compared to the Boolean map for rubber under medium fallow period

		Fuzzy Suitability					Total
	Class	**0***	**S1**	**S2**	**S3**	**N**	
Boolean Suitability	**S1**	204	245398	203296	12992	792	462682
	S2	120	221625	219510	8376	1707	451338
	S3	0	69509	383618	498977	23056	975160
	N	0	5435	12923	73676	246661	338695
	Total	324	541967	819347	594021	272216	2227875
Fuzzy Agreement		-	45.3	26.8	84.0	90.6	

*Cells no evaluated under the fuzzy classification

Table 12 Agreement of Boolean map compared to the fuzzy map, mean agreement, areal difference and parameters for kappa statistic per suitability class for rubber under medium fallow period

Class	Boolean Agreement (%)	Mean Agreement (%)	Areal Difference (%)	d_i	q_i	Kappa per class (%)
S1	43.9	48.9	-17.1	245398	2.5E+11	30.94
S2	48.6	34.5	-81.5	219510	3.7E+11	8.19
S3	51.2	63.6	39.1	498977	5.8E+11	71.54
N	72.8	80.8	19.6	246661	9.2E+10	88.93

Table 13 Overall maps agreement and kappa statistic for comparison of fuzzy and Boolean map for rubber under medium fallow period

Overall Agreement	Kappa (%)	d	q	N
54.3	38.3	1210546	1.3E+12	2227875

Table 14 Summary of percentages of areal agreement

Models	Land Utilization Type	No Fallow		Medium Fallow		Old Fallow	
		Kappa (%)	% Agreement	Kappa (%)	% Agreement	Kappa (%)	% Agreement
Boolean vs. Fuzzy	Upland Rice	9.9	31.8	-2.5	18.4	-2.3	18.26
	Rubber	33.2	52.1	38.3	54.3	33.4	52.4
Boolean vs. Farmers	Upland Rice	-3.0	35.4	-3.0	35.4	-3.0	35.4
	Rubber	-1.0	23.9	-1.0	21.7	-1.0	23.9
Fuzzy vs. Farmers	Upland Rice	-30.0	38.2	-30.0	38.2	-30.0	38.2
	Rubber	-10.0	21.7	-10.0	21.7	-10.0	21.7

6 DISCUSSION: WHOSE REALITY COUNTS?

FAO (1976, 1983, 2007) offers a framework, which is adaptable. The experts' classification relies on experience for assigning the importance of land qualities and land characteristics, within decision trees in the case of a Boolean approach, or pair-wise comparison matrices in the case of fuzzy weights determination. The experts' suitability assessment included feedback from the farmers regarding land tenure, workability and influence of fallow period which may not be precise. Fallow was introduced in the models as a land characteristic that affects workability and fertility, but no physical measurements were made to determine its exact impact on these land qualities.

In contrast, the land evaluation performed by the farmers is a 'preferred land allocation' that takes into account the current status of the plots, their traditional use and the fallow conditions of the plot at the moment of the evaluation. In other words, land suitability evaluation is only a small fraction of what farmers do. For both land utilization types, areas that the farmers classify as suitable resulted as not-suitable according to the fuzzy and the Boolean methods, being the disagreement higher for rubber; this could be attributed to the lack of adequate know-how on this crop. Interviews led to conclude that farmers identify areas suitable for rubber not based on their own experience, but on the experience of farmers in other areas, on the current land use and management in the area, and on their hope and expectations. The maps created by the farmers can be improved to be used in comparisons by requesting them to categorize the suitability with four classes as in the FAO frameworks. In the same way, a detailed survey on fallow and a study on effect in fertility and workability can improve both experts models.

Fuzzy- and Boolean-based methods differ due to the suitability reclassification of the fuzzy maps. In fuzzy modeling the limits between suitable and not suitable are not as strict as in the Boolean; therefore the suitability levels have been defined by grouping cells with similar values using the natural breaks of the

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raster map histogram. Under fuzzy, an area can be classified as S1 with a membership value that is not so close to 1, while in the Boolean theory (maximum limit method) it is required that all the parameters for that soil unit have a S1 class, equivalent to having a value of 1 under fuzzy.

To control and track the factors affecting the suitability of a plot is relatively simple with the Boolean method, while in the fuzzy model it is necessary to review the interaction between membership functions and weights, which is not a straightforward process.

Fuzzy classification allows intermediate possibilities of suitability beyond the traditional classes given by the Boolean models, but it can over- estimate the potential of a land unit depending on how the limits of the suitability classes are assigned. A careful assignment of weights under the PCM and of the fuzzy operations is necessary to avoid misclassifications.

The structure of the maximum limitation method makes the assessment rigorous: it requires the same value of suitability classes for every single land characteristic to avoid falling into the next suitability class (for instance, all the land characteristics with values of s1 [partial suitability] to avoid falling from S1 to S2 class). The selection of land characteristics, their limits, and how they interact within the decision trees is a sensitive issue when performing the evaluation. Parameters such as workability or distance, that may be relatively less important for the physical suitability, are decisive for the final result of the evaluation. In the study area, a plot that physically is suitable (S1) may be reduced in class (to S2, for instance) or in order (to N) if it is located too far away from the villages or if it is difficult to work on it. To cope with the constraints of the maximum limitation method, alternatives such as parametric indices can be employed (see for instance Koreleski, 1988; McRae and Burnham, 1981) which are based on numerical factors for land qualities that combined provide a single rating to the land unit, similarly as it is done with assignment of weights in the fuzzy method.

7 CONCLUSION

The Fuzzy and Boolean models share the same fundamental concepts of land suitability evaluation but differ in their methodology. Input from the farmers related to land utilization types and non-physical parameters that affect suitability were introduced in the experts' approaches. The results from both experts' classifications showed an agreement in the percentage of area considered as suitable, but disagree in the suitability classes obtained. Using the fuzzy-based model highly suitable areas were found for both rubber and upland rice, and the comparison with the farmers showed a better correspondence.

The farmers' classification has a better agreement with the experts' for upland rice than for rubber, which seems to be related to the lack of knowledge on the latter. In their classification farmers take into account the current and preferred land uses. The preferred land uses, in the process of land use planning, are indeed one step further than land suitability evaluation.

The use of Boolean and fuzzy based classifications, combined with input from farmers, can be successfully applied to improve land evaluation studies but the experience of the land evaluator is decisive for the final results.

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خووان فرانسیسکو سانچز-مورنو[1]، عباس فرشاد[2] و پیتر پیلشو[3]

۱- ITC، انشده، هلند
۲- دانشیار، مرکز GIS، دانشگاه لوند، سوئد

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چکیده درآمد حدود ۸۰ درصد مردم از کشاورزی تامین می‌شود و برنج خوراک اصلی آنان است. توپوگرافی منطقه، کشت برنج در مناطق بالا دست را ایجاب می‌کند. هرچند که زارعین فاقد معلومات کافی از کم و کیف کشت و برداشت و پرورش کائوچو می‌باشند اما اخیرا بازار چین در ترغیب زارعین برای کشت درخت کائوچو نقش بزرگی داشته است. در این مطالعه ارزیابی تناسب اراضی برای دو محصول برنج و کائوچو و مقایسه بین نقطه نظر کشاورزان و کارشناس هدف قرار داده شده است. دو مورد از سه روش انتخابی بر پایه معلومات کارشناسی و مورد سوم بر پایه کار گروهی زارعین است. کارشناس از روش‌های فازی و بولی کمک می‌گیرد. بر طبق نتایج روش بولین ۸۸ درصد اراضی مناسب برای کشت برنج و ۸۵ درصد مناسب برای کائوچو و بر طبق نتایج روش فازی نیز ۸۹ درصد اراضی مناسب برای برنج و ۸۸ درصد مناسب برای کائوچو می‌باشند. اما نتیجه‌ای که طبق نظر زارعین بدست آمد حاکی از تناسب ۳۷ درصد اراضی برای برنج و ۱۴ درصد برای کائوچو است که به مراتب کم‌تر از روش فازی است و علت آن در این مطالعه مورد بحث قرار داده شده است. در نهایت مشخص شد که تناسب اراضی طبق نظر زارعین در مورد برنج قابل قبول‌تر از کائوچو است و علت آن هم فقدان تجربه در کشت و مدیریت درخت کائوچو می‌باشد.

کلمات کلیدی: ارزیابی اراضی، تئوری بولی، تناسب اراضی، منطق فازی، نرم‌افزار آلس