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Soil Sustainability Assessment for Rice Cropping Recommendations: A Case Study in An Giang Province, Vietnam

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ABSTRACT

Background: The study aimed to identify the sustainability of soil fertility and social-economic factors for major rice cropping and offer suggestions for sustainable rice cropping.

Methods: The kite sustainability assessment is a multi-objective assessment method based on standardized scoring formulas built on land assessment criteria with limiting factors. It used the AHP method to determine how different critical factors affect whether a place is good for growing rice. Therefore, determining soil fertility, economy and society has essential implications for rice cultivation in the study area.

Result: The soil fertility status of the two main rice crops in the study area has a low pH, high organic matter content, high cation exchange capacity and high clay content. Besides, the soil has a good water-holding capacity, a high total N content and an average total P content. Utilizing the AHP method, it was determined that soil fertility, economic and social factors were the second-most significant factors in determining the suitability of land for agriculture as well as the possibility and performance of rice. While the double-rice cropping model is only sustainable regarding fertility, the triple-rice cropping model achieves the sustainability goal of economic, social and soil fertility indicators. Two rice cropping seasons, lWS-mSA (double rice) and mWS-eSA-eAW (triple rice) achieve a balanced level in all indicators of level 2 of soil fertility. Therefore, in both models, a system that reaches a sustainable level exists. Even so, the lWS-mSA cropping season could be less environmentally harmful than the mWS-eSA-eAW season regarding the environmental group.

Key words: Agricultural land, AHP, Cropping season, Fertility, Kate model.

INTRODUCTION

In the Mekong Delta, Vietnam, rice is the main crop in the region's agricultural development. The present condition is affected by many influencing factors and rice is regularly farmed under irrigation (typically in rotation with other crops) (Minh *et al.*, 2020). Still, this high productivity leads to unsustainable water and soil exploitation, inefficient chemical input use and a threat of disease and insect and pest problems. Otherwise, it is necessary to identify the primary factors in land resources to improve efficiency for a more sustainable rice yield. Over the past 20 years (1995-2015), rice production in the Mekong Delta (MRD), Vietnam, has steadily increased, averaging 0.02%/year in planted area and 0.04%/year in yield. The purpose of rice production during this time is to meet production targets rather than to raise quality (Minh *et al.*, 2022). In addition, rice is one of India's most important food crops and a major food source. It is grown on a total area of 43.09 million hectares and produces 106.30 million metric tons annually. According to A. Baishya et al. (2017), this rice predominates the agricultural landscape of Assam in India's North-East.

An Giang province is significant for agriculture and rice cultivation. As a result, farming and using agricultural resources is a contentious local issue. Land quality has been impacted, particularly in the context of the accelerating evolution of climate change and the risk of deterioration of natural resources owing to full soil exploitation for economic development. The province's soil fertility is currently declining. The fertility reduction in the area is, however, often at a modest level. However, the soil chemical characteristics have dramatically decreased in places with arable land, such as rice fields near dike edges, vegetable producing areas, *etc.* and forestry fields in low hills with steep slopes (Tran Thi Ngoc Diep, 2018). Soil fertility parameters were determined for different land use types, soil sustainability was assessed for different land use types and solutions for the sustainable use of agricultural land on soil fertility were suggested.

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MATERIALS AND METHODS

Study location

According to the land statistics for 2017 and 2018, An Giang province has a total area of 353.7 thousand hectares. Equal to 1.07% of the country's area and ranks fourth in the

Mekong Delta. The agricultural production land is 298.7 thousand ha, accounting for 84.45% of the entire region (Fig 1). The specific production status of the study area includes the primary land use types, including triple and double rice cropping models. However, it has formed due to the diversity of water regimes, soil quality, topography, ecology and farming practices. As a result, rice cultivation models have different crops (early, main and late seasons).

Data collection

Secondary data collection

The study inherits and synthesizes scientific reports and land statistics data from 2017 to 2018 on assessing potential soil fertility and documents on previous studies related to the topic. They also inherit household interview survey data and analyze soil samples from An Giang province during the dry season from 2020 to 2021.

Primary data collection

Twenty households cultivating rice were interviewed on productivity, area, price of rice purchased from traders, total revenue, expenditure and profit. In addition to profitability and capital efficiency, most of the data collected for soil fertility, socio-economics and the environment is used for AHP analysis.

Besides, PRA interviews people in the commune, including the chairman or vice president of the commune, the commune cadastral officer, the commune agricultural officer, or another commune official with experience in the area.

The form of the survey is mainly based on the questionnaire.

Soil fertility evaluation

Based on the chemical analysis results to determine the type of mechanical components, select the related physical and chemical properties to evaluate the fertility.

Sustainability of soil fertility evaluation

The kite sustainability assessment method is a multi-objective assessment method based on standardized scoring formulas built based on FAO (2007) land assessment criteria and other approved studies and implemented in the Mekong Delta (Roan Ngoc Chien, 2001; Vu, P. T., *et al*., 2013).

Economic goal

According to the method of rate transformation, reduce to the value 0-1.

Social goals

Determined by qualitative assessment and applied to three criteria, including technical level, cultural level and labor.

Soil fertility

Determined by the criteria of pH, EC, CEC, soil texture and organic matter, determined at 20 survey points. Determine issues' value (social, economic and soil fertility) using a 5-level rating scale and convert from qualitative to quantitative (Roan Ngoc Chien, 2001).

Analytical hierarchy process (AHP)

The analytical hierarchy process (AHP) can be used as a consensus-building tool in situations involving a committee or group decision-making (Saaty, 1980). AHP is a procedure that seeks to consider the context of the spatial planning decision by identifying and arranging the criteria into different groups (Vogel, 2008). Assessing the relative importance of factors to analyze the suitability of land for agriculture using the AHP method indicated that soil fertility, economic and social factors were the second essential factors in assessing land suitability and the possibility and performance of rice. The weighting of parameters for AHP suitability can be estimated using the geometric mean method.

The data processed for economic, social and fertility goals have yet to be aggregated and compared because of the difference in measurement units. Therefore, to solve this problem, the topic applies the normalization method of dividing by the most significant value to convert values to the same measurement team from 0 to 1 (1). This method has been applied in studies in the Mekong Delta (Van Pham Dang Tri, 2001; Nguyen and Ngo 2013). The evaluation criteria address land suitability decision-making based on i) land use, ii) soil fertility, iii) economic and iv) social factors.

Scores for these factors are calculated using the formula:

$$\text{LUT factor score (j) (i)} = \frac{\text{The factor score (j) of the LUT (i)}}{\text{Factor (j)-max}} \quad ...(1)$$

Where:

The factor score (j) of the LUT (i)= Value of the selection factor (1 out of 3 sub-objectives) of the LUT (i) converted from qualitative to quantitative.

Factor (j)_max= Highest value of the selection factor in all land use types.

The objectives' priority order (assignment of emphasis) is determined by interviewing farmer households.

The priority factor is determined by applying the expected value formula based on the priority order of the objectives (Sharifi M.A, 1990).

$$E(\gamma_j) = \sum_{n\to 0}^{j-1} \frac{1}{j\,(j\text{-}n)} \quad ...(2)$$

Where:

$E(\gamma_j)$= Target's expected value;

j= Number of targets to be ranked.

The combined effect score was calculated using formula (3) based on the weighted and normalized scores of the economic, social and fertility goals.

$$W_i = X_i \times E(\gamma j) \quad ...(3)$$

Calculation score for each goal:

Social efficiency Score =

(Technical priority coefficient × technical score) + (cultural level priority coefficient × cultural level score) + (Labor priority factor × points some workers).

The fertility target score was calculated using the formula:

Fertility score =

(pH_{H2O} coefficient × Point of pH_{H2O}) + (% organic matter × Points of percentage organic matter) + (CEC × Points of CEC)+(Texture × Points of texture) + (% total N × Points of total N) + (% total P × Points of total P).

The priority factor is determined by applying the expected value formula based on the priority order of the objectives (Sharifi M.A, 1990). Proposed order of priority of land use types.

Use Excel software to draw charts showing the sustainability of the models.

RESULTS AND DISCUSSION

Soil fertility properties of different land use

The analysis results on the soil fertility characteristics of the main land use types in the province show that:

The values pH, organic matter (OM), total N, total P, cation exchange status capacity (CEC) and soil structure describe the soil fertility state of An Giang province's two main uses.

According to Tables 1 and 2, the pH value of the triple rice crop (5.77) is higher than the double rice crop (5.15). The percentage of the organic matter content of the triple rice crops (3.19) is lower than that of the double rice crops (3.96). The cation exchange capacity in the soil of the triple rice crops (14.08) was higher than that of the double rice crops (13.46). The soil texture of the triple rice crops belonged to the medium form, while the double rice crops had a heavy texture. The soil N content of the triple rice crops (0.19) was lower than that of the double rice crops (0.25) and the P content of the triple rice crops (0.08) was lower than that of the double rice crops (0.09).

The analysis results from Table 3 show that the average soil pH value for the lWS-mSA season of the double rice cropping model (6.77) is the highest and the lowest value is the mWS-eSA of the double rice cropping model. (4.75). It shows that the triple rice cropping model's pH is more stable than the double rice cropping model. Generally, the percentage of organic matter in the double rice cropping model is higher than that of the triple rice cropping model. The soil cation exchangeable capacity in these models is average, which shows that the soil has an increased ability to hold and exchange nutrients. According to the analysis results, the highest percentage of total nitrogen content was in the mWS-eSA season (0.33%) and the lowest was in the lWS-mSA season (0.12%) of the two-crop rice models. The system of the triple-crop rice model is somewhat more stable but still lower than that of the double-crop model. The percentage analysis of the total phosphorus content of the two models in the triple-crop rice model and the double-crop rice model shows that the P content of the models in the double-crop rice model is higher than those in the triple-crop rice model.

The two primary rice farming systems in the research area have different soil fertility levels. In which the soil nutrient status of the triple rice model is lower than that of the double rice model.

Soil sustainability analysis for major cropping recommendations

Based on the initial weight assigned to each indicator from the AHP analysis, normalize the data into an assessment score based on each soil property indicator and its weight.

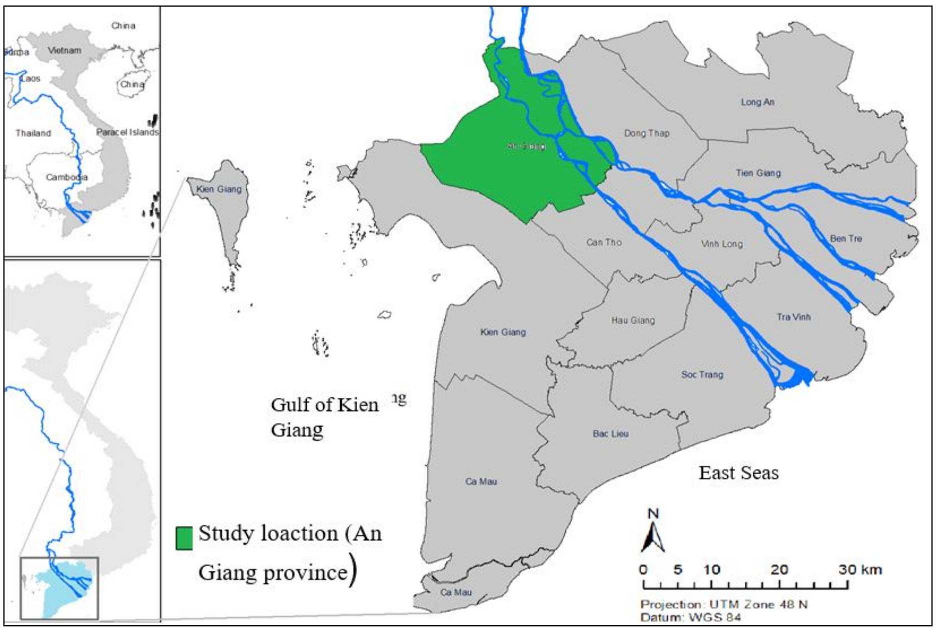

Fig 1: Study location in the Mekong delta, Viet Nam.

The results of the evaluation of the fertility target for the land use types are presented in Fig 2. Regarding the fertility target of the rice growing models of the two models, triple and double rice cropping, the evaluation scores are pretty high.

The most appreciated system in the double rice cropping season is IWS-mSA. This model is highly respected in the total of 3 designs because it is guaranteed in all aspects (cation exchange capacity, percentage of total phosphorus and total nitrogen, the soil texture is assessed as appropriate compared to the crop and sustainability in many criteria). On the other hand, the most sustainable model for the triple rice cropping season is mWS-eSA-eAW because the requirements (high organic matter content, good cation exchange capacity, or CEC and a high percentage of total nitrogen) are guaranteed. However, the remaining two indicators, pH_{H2O} and total phosphorus, still have relatively high values.

From the indicators' analysis, overlapping the seasonal model chart on the three socio-economic goals and soil fertility is performed. The results are shown in Fig 3.

Sustainability analysis for major cropping recommendations

Sustainability assessment for triple rice cropping

The kite chart showing the sustainability of the triple rice cropping models shows that the social and fertility goals have similar high scores, almost reaching the level of sustainability. However, the economic objective is more rigid than the other two goals.

Therefore, the triple rice cropping model has not achieved sustainability on three goals. The economic target is too high because people have intensively cultivated more crops with triple crops. It brings high economic benefits and increases income for people. Still, it is not encouraged by the government and researchers because of the increase in rice cultivation for the third crop due to the deterioration of soil quality and fertility (acidic soil, loss of silt and clay particles in the soil layer surface, loss of organic matter, depletion of nutrients), which affects the land use of the next generation. The continuous production of 3rd rice cropping models for many years has made the soil fertile. Therefore,

Table 1: Properties of triple rice soils.

	Soil properties				
	pH_{H2O}	%OM	CEC	% Total N	% P_2O_5
Min	3.92	0.98	11.54	0.09	0.05
Max	6.46	6.67	16.54	0.35	0.15
Std	0.74	1.61	1.83	0.09	0.03
Var	0.62	2.96	3.85	0.01	0.001
Average	5.77	3.19	14.08	0.19	0.08

Table 2: Properties of double rice soils.

1	Soil properties				
	pH_{H2O}	%OM	CEC	% Total N	% P_2O_5
Min	3.90	1.13	10.23	0.08	0.05
Max	7.41	6.15	17.23	0.52	0.16
Std	0.98	1.43	1.96	0.12	0.03
Var	1.04	2.23	4.19	0.01	0.001
Average	5.15	3.96	13.46	0.25	0.09

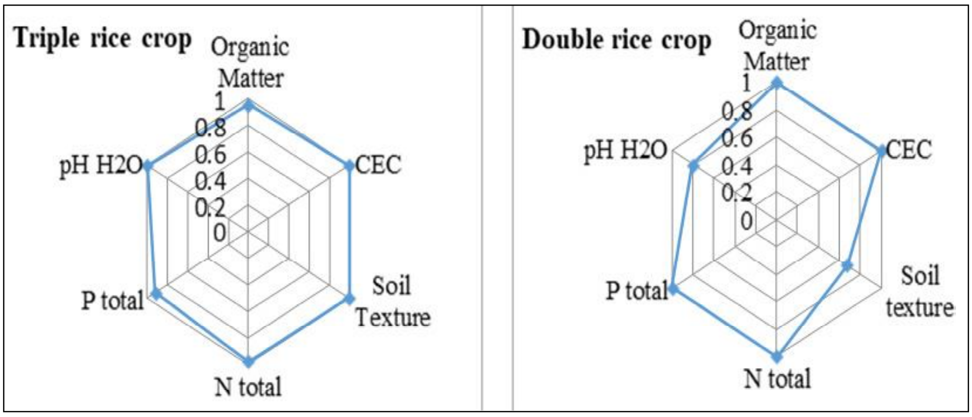

Fig 2: Sustainability analysis for level 2 fertility target of land use types.

to have good rice, farmers have no choice but to fertilize a lot, which increases production costs. But triple rice cropping cultivation can easily cause many pests and diseases, organic poisoning and soil nutrient depletion due to the thorough exploitation of the land. However, this model has high consensus among farmers and strong support from state organizations to build large-scale specialized farming areas and large sample fields. The technique is increasingly improved and the Autumn-Winter rice crop (3rd cropping season) is still essential to the locality. Because this is a rice production to provide quality seeds for the next Winter-Spring crop, the isolation period is too long, not guaranteeing the germination rate if using seeds from the Summer-Autumn crop. Therefore, three-crop rice cultivation is given maximum attention and has strategic significance in the agricultural development model of the province. According to the assessment, the triple rice cropping model has a reasonably good impact on the environment, according to the evaluation of farmers, possibly because people have not seen all the harms of continuous cultivation of the triple rice cropping model. If not handled well, it can cause significant damage to the ecology. Most people are unaware of environmental protection when agricultural production and pollution due to fertilizers and drugs occur frequently. The land is degraded due to unreasonable cultivation and nutritional supplementation is unbalanced and unscientific, so the quality of the land is degraded. Triple rice cropping models require a closed dike system to protect rice, reducing the biodiversity of natural wetlands.

Sustainability assessment for double rice cropping

The analysis of the level 1 indicator, including economic, social and fertility goals and the cropping patterns of 2 promising farming models in Fig 4, (a) triple rice and (b) double rice, shows that the model is balanced and optimal among all 3 destinations. Therefore, the target is the triple rice cropping model. Furthermore, the evaluation score for each objective is much higher than the double rice cropping model, achieving stability between the three factors. However, the remaining double rice cropping models, which do not guarantee all 3 goals, are poor at achieving one goal in another, such as completing a high value at the fertility target but having economic efficiency. Therefore, improving the model's economic efficiency is necessary and it needs more support from all levels, authorities and organizations. Nevertheless, based on the multi-objective assessment of the main promising land use models of An Giang province, it is possible to draw a sustainable land use model, which is the triple rice crop model.

The results of the evaluation scores after standardization of the triple crop rice model are, respectively, economic (1.0), social (0.96) and fertility (0.98). The kite

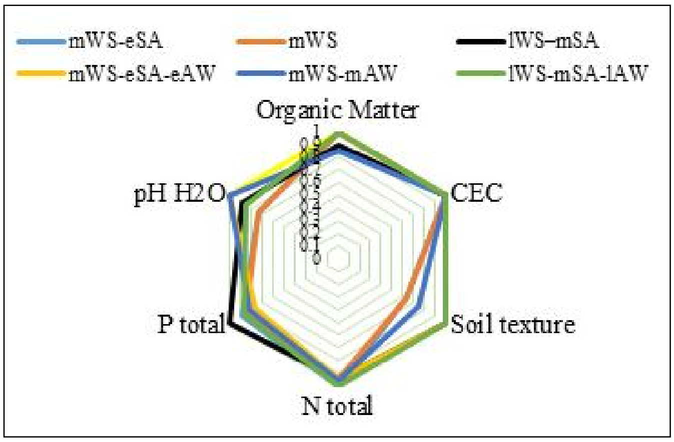

Fig 3: The chart of comparison of fertility indicators among rice cropping models.

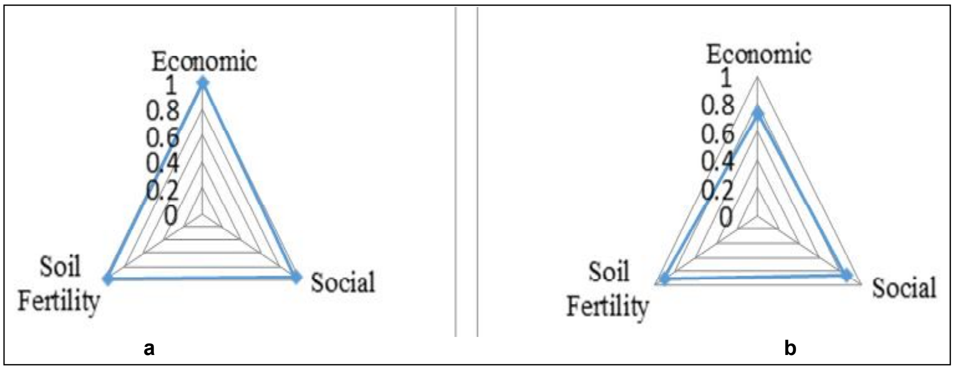

Fig 4: Sustainability assessment chart of the triple (a) and double (b) rice cropping models

chart to evaluate the sustainability of the model is shown in Fig 4(a). The results of the evaluation scores after standardization of the double rice crop model are economic (0.73), social (0.85) and fertility (0.91), respectively. The kite chart to evaluate the sustainability of the model is shown in Fig 4 (b).

The double rice cropping model has a lower rating than the triple rice cropping model. This model is economically limited while achieving relatively high social and fertility efficiency. It can be explained that this model of farming does not cause much harm to the environment, as when cultivating triple rice crops, triple rice is socially influential. Still, because of the abandonment of the third crop, the economic efficiency is not high. Therefore, the economic efficiency of the double rice cropping model is assessed to be worse than that of the triple rice model. The advantage belongs to the double rice cropping models in terms of evaluation between the two models. The current trend is oriented toward applying the integrated farming model, a combination of rice and other uses such as fish, upland crops, etc. So with the existing economic efficiency of the double rice cropping models, it is pretty good to move to integrated farming models. The fertility efficiency is almost absolute, with a normalized value of 0.91.

Carrying out the overlapping of the sustainability assessment charts on the level 1 criteria of all land use types, we can compare the sustainability of all 3 objectives of the models together, then choose to develop a promising model to ensure sustainable development.

Overall assessment

The overall analysis of level 1, including three economic, social and fertility goals, in Fig 5, concurrently with different promising rice farming models, shows that the model achieves a balance and optimality between all three goals. It is the triple rice cropping model. The evaluation score for each objective is much higher than the double rice cropping model, achieving stability between the three factors. The remaining model is two-crop rice, which does not guarantee all three goals. Achieving this goal is poor for other purposes, such as achieving a high value at the fertility target of 0.91

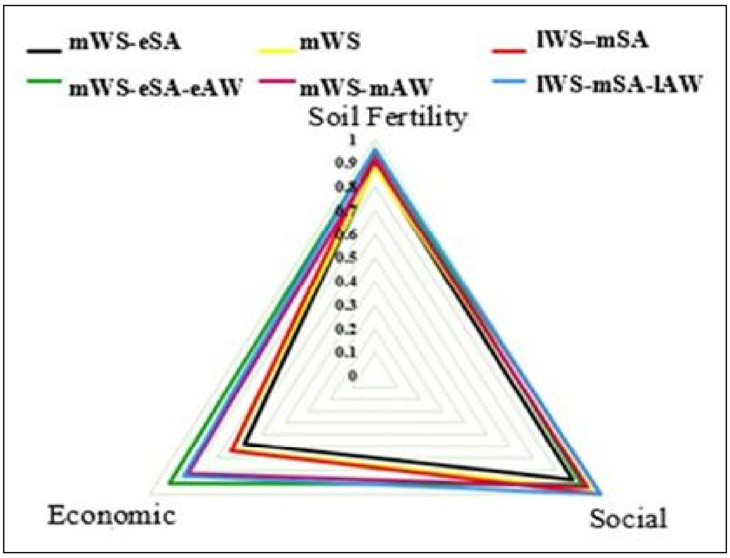

Fig 5: Summary of sustainability assessment on difference rice cropping models.

Table 3: Status of soil fertility of different rice cropping models An Giang province.

LUT / Soil properties	mWS-eSA	mWS	IWS-SA	*mWS-eSA-eAW*	mWS-AW	*IWS-mSA-IAW*
pH $_{H2O}$	4.75	4.91	6.77	5.5	6	5.83
Organic matter (%)	7.7	7.55	2.87	6.42	2.87	3.12
CEC (meq/100g)	12.76	14.58	12.39	13.44	15.38	13.11
N total (%)	0.33	0.22	0.12	0.23	0.2	0.16
P total (%)	0.09	0.08	0.11	0.1	0.07	0.07

*mWS-eSA: Doube Rice (*Main Winter-Spring and Early Summer-Autumn cropping season).

mWS: Mono Rice (Main Winter-Spring cropping season).

IWS-mSA: Double Rice (Late Winter-Spring and Summer-Main Autumn cropping season).

mWS-eSA-eAW: Triple Rice (Main Winter-Spring and Early Summer-Autumn and Early Autumn-Winter cropping season).

mWS-AW: Double Rice (Main Winter-Spring and Autumn-Winter cropping season).

IWS-mSA-IAW: Triple Rice (Late Winter-Spring and Main Summer-Autumn and Late Autumn-Winter cropping season).

but having low economic efficiency. Therefore, improving the model's economic efficiency is necessary and it needs more support from all levels, authorities and organizations. Based on the multi-objective assessment of the main promising land use models of An Giang province, it is possible to draw a sustainable land use model, which is a triple rice cropping model.

CONCLUSION

The results can conclude that the two primary rice farming systems in the research area have different soil fertility levels. In which the soil nutrient status of the triple rice model is lower than that of the double rice model. Utilizing the AHP method, it was determined that soil fertility, economic and social factors were the second-most significant factors in determining the suitability of land for agriculture as well as the possibility and performance of rice. The geometric mean method can be used to estimate the weighting of the parameters for AHP suitability. In addition, data normalization is found to evaluate the multi-criteria of soil fertility sustainability.

The triple rice cropping model achieves the sustainability goal of economic, social and soil fertility indicators, while the double rice cropping model is only sustainable regarding fertility. However, the model that achieves a balanced level in all indicators of level 2 soil fertility is two rice cropping seasons, lWS-mSA and mWS-eSA-eAW. Therefore, both seasons have a system that reaches a sustainable level. Still, regarding the environmental level, the lWS-mSA season has a less adverse impact on the environment than the mWS-eSA-eAW season.

Conflict of interest: None.

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