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Research Article

Fuzzy Multicriteria Decision-Making for Ranking Intercrop in Rubber Plantations under Social, Economic, and Environmental Criteria

Jitsupa Muangman,[1] Kittipong Krootsong,[1] Phattamon Polrong,[1] Weera Yukunthorn ,[2] and Weerawat Udomsap[3]

[1]*Faculty of Management Sciences, Phuket Rajabhat University, Phuket 83000, Thailand*
[2]*Faculty of Science and Technology, Kanchanaburi Rajabhat University, Kanchanaburi 71190, Thailand*
[3]*Faculty of Humanities and Social Sciences, Kanchanaburi Rajabhat University, Kanchanaburi 71190, Thailand*

Correspondence should be addressed to Weera Yukunthorn; w.yukunthorn@kru.ac.th

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Rubber price instability causes great economic problems for rubber plantation in Thailand. Intercropping is an alternative way for rubber farmers in problem-solving. In this paper, we established decision-making system for plant selection in rubber fields under social, economic, and environment criteria with the use of fuzzy multicriteria decision-making (FMCDM) to rank plant options. Firstly, we modified the traditional FMCDM by defuzzification with norm centroid and developed the fuzzifier maps the norm centroid to triangular fuzzy number (TFN). According to fuzzification, the final rating evaluation of plant options are determined by total utility values. Finally, ranking of the plant options is obtained. Our modifications provided an alternative decision-making process with softer computational capability compared with the traditional method. In addition to soft computing, data visualization and analysis of the possibility in each factors could be investigated. This decision-making system was implemented in Phang-Nga Province, Thailand. Its outputs assisted the rubber farmer in selecting suitable plants for cultivation. Pros and cons of each plant options and area-based approaches were easily seen by data visualizations. This decision-making system provided beneficial information which support precision developments for rubber farmer and government agencies.

1. Introduction

Rubber is one of the major crops cultivated in south of Thailand, and this is region possessed the largest area of rubber plantation [1]. Recently, fluctuation of rubber price affects farmer's livelihoods. Intercropping of rubber tree plantations has been a strategy for earning higher incomes from the rubber crop [2]. The challenge of rubber intercropping in the 21st century is analysed considering not only physical environments but also socioeconomic and environments. So, plant selection under suitable area-based plantation conditions will be sustainable for rubber farming [3].

The suitable plantation conditions could be determined by several criteria under social, economic, and environmental factors. MCDM is a mathematical tool with capability in importing both of qualitative and quantitative data. In addition, it is a powerful method for solving the complex decision problems. Applications of MCDM could be found in various fields such as business and management, economics, education, and agriculture [4–7]. Previously, MCDM had been applied on selecting intercrops in the rubber field under geographic criteria and economic criteria in Phitsanulok province, Thailand. They compared the use of analytical hierarchy process (AHP), the technique for order preference by similarity to ideal solution (TOPSIS), and the simple additive weighting (SAW) in computation [8].

The computation of uncertain problems without observing the existence of events is well known as fuzzy set theory. An application of the fuzzy set couple to MCDM is to develop FMCDM and has been proved to be successful in several real-life problems [9]. In FMCDM, the linguistic data are evaluated in forms of fuzzy numbers. Ranking is performed using techniques of ordering fuzzy numbers [10–12]. The new techniques in computation are being currently developed, for example, using the FVK module in Excel [13] and using centroid of fuzzy numbers [14].

Ranking with centroid is an interesting method according to the data collection of FMCDM analogous to the tensor model. If we use defuzzification technique with centroid norm of each fuzzy number, the tensor data would approach to the matrix of real numbers. So, this methodology is softer computing. This technique was developed by Chen in 1997 [15] for solving the tool steel-material selection problem under fuzzy environments [16]. The trapezoidal fuzzy number of the linguistic term is characterized by its centroid and ranked on simple arithmetic operations. It differs from the original problem which is computed on fuzzy arithmetic and is ranked by the total utility function as follows: let U be a fuzzy set; the utility of fuzzy number $A_p = (a_1^p, a_2^p, a_3^p)$ is defined by

$$U\left(A_p\right) = \frac{1}{2}\left[1 + \frac{a_3^p - l}{(u - l) + \left(a_3^p - a_2^p\right)} - \frac{u - a_1^p}{(u - l) + \left(a_2^p - a_1^p\right)}\right], \tag{1}$$

where l and u are infimum and supremum of membership functions.

In fact, the trapezoidal fuzzy number (TrFN) of the rating scale was extended from TFN by repeating the core of fuzzy shape. For example, a very high level TFN (0.7,1,1) is extended to TrFN (0.7,1,1,1). By considering the use of centroid of TFN (0.7,1,1) = 0.9 and the centroid of TrFN (0.7,1,1,1) = 0.925, the squares are equal to 0.81 and 0.855625, respectively. We see that the multiplication of the best level would obtain the decreasing value. In this study, the improvement of multiplication of centroids and the development of computation for decision-making process including an investigation of the decision-making system in ordering intercrop rubber tree plantation under social, economic, and environmental criteria were established. This paper is organized as follows. In Section 2, mathematical tools and computation on norm centroid of TFN are developed. The defuzzification-fuzzification technique was established for the ranking process with total utility values. In Section 3, the present decision making system for plant selection and ranking processing via FMCDM on norm centroid are discussed. In Section 4, we illustrate an application of decision-making system which provides recommendations to the rubber farmer, and the last section presents the conclusion and discussions relative to development and implementation of results.

2. Development of Mathematical Tools and Computation

In this section, we will develop fuzzy computing on the norm centroid. By considering the TFN used in this work, it is considered as a subset of $[0,1]^3$. Let $x = (x_1, x_2, x_3)$ be a TFN such that $x_1 \le x_2 \le x_3$ and let x and y be TFN, and the addition and multiplication are formulated as follows [13]:

$$\begin{aligned}(\text{Addition})\ x + y &= \left(x_1 + y_1, x_2 + y_2, x_3 + y_3\right),\\ (\text{Multiplication})\ xy &= \left(x_1 y_1, x_2 y_2, x_3 y_3\right).\end{aligned} \tag{2}$$

Based on the abovementioned computational method, one operation of the two TFNs corresponds to three operations of real numbers. Therefore, big TFN data yield a huge computing. To reduce the complexity of computation, the hard computing is replaced by a soft computing which is called the defuzzification method [14]. By this technique, one operation of the 2 TFNs corresponds to one operation of the centroid.

2.1. Modified Defuzzification and Significance. As mentioned previously, the multiplication of centroid reduces the level of decision-making. So, we will modify the defuzzification of linguistic terms by norm centroid in this section. Let $x, y \in V \subset [0,1]^3$ and $t \in \mathbb{N}\backslash\{1,2\}$, a fuzzy norm $\|\odot\|_t\colon V \longrightarrow [0,1]$ is defined by

$$\|x\|_t = \frac{\left(x_1 + x_3\right) + (t-2)x_2}{t}. \tag{3}$$

Centroid usage of linguistic terms in [15]is recalled. The linguistic terms associated with TFN (a, b, c) are extended to TrFN (a, b, b, c) and defuzzified with $(a + c + 2b)/4$. It is obviously seen that the defuzzification is $\|\odot\|_4$. If we consider the confidence level at 100% = 1.0, then 95% = 0.95. We assume that the multiplication of centroids is about 0.95 which belongs to $t = 12$. So, throughout this work, the use of $\|\odot\|_{12}$ has been implemented in our decision-making system. The five levels of importance are denoted as follows: NI: = not important, LI: = less important, OI: = ordinary important, I: = important, and VI: = very important. Similarly, the five levels of possibility are denoted as follows: I: = impossible, WP: = weak possibility, OP: = ordinary possibility, P: = possible, and SP: = strong possibility. The grey level is computed by RBG $*$ $\|\odot\|_{12}$ as shown in Table 1.

The fuzzy norm of addition and multiplication is straightforward:

$$\|x + y\|_t = x_t + y_t, \tag{4}$$

$$\|xy\|_t = \|x\|_t \|y\|_t - E(x, y). \tag{5}$$

To approximate $\|xy\|_{12}$ by $\|x\|_{12}\|y\|_{12}$, the errors in Table 2 are verified by

$$E(x, y) = \left|\|x\|_{12}\|y\|_{12} - \|xy\|_{12}\right|. \tag{6}$$

Hence, $\forall x \in V \forall y \in V, E(x, y) < \max\{E(\cdot,\cdot)\} < 5 \times 10^{-2}$. Therefore, this method provides two significant digits.

Table 1: Association between linguistic terms, fuzzy numbers, and their norms.

	NI/I	LI/WP	OI/OP	I/P	VI/SP
TFN	(0,0,0.3)	(0,0.3,0.5)	(0.2,0.5,0.8)	(0.5,0.7,1)	(0.7,1,1)
$\|\odot\|_3$	0.1	0.27	0.5	0.73	0.9
Grey					
$\|\odot\|_2$	0025	0.29167	0.5	0.708333	0.975
Grey					

Table 2: Errors of multiplications.

$E(x,y)$	NI/I	LI/WP	OI/OP	I/P	VI/SP
NI/I	0.00688	0.00521	0.00750	0.00729	0.00063
LI/WP	0.00521	0.01076	0.01250	0.01007	0.00729
OI/OP	0.00750	0.01250	0.01500	0.01250	0.00750
I/P	0.00729	0.01007	0.01250	0.01076	0.00521
VI/SP	0.00063	0.00729	0.00750	0.00521	0.00000

2.2. Fuzzification. In the final state of traditional fuzzy MCDM, we applied (1) to the final rating fuzzy scores. So, we need to establish a fuzzifier which transforms the range of $\odot_t$ to TFN. Figure 1 is considered, and let $x^1 = (x_1^1, x_2^1, x_3^1)$ and $x^2 = (x_1^2, x_2^2, x_3^2)$ be TFN of consecutive rating scale in V.

To construct the triangular shape of x^* from its norm, we consider the ratios of the lower and upper norms. Assume that $x^* = (x_1^*, x_2^*, x_3^*)$, we get

$$\frac{x_i^* - x_i^1}{x_i^2 - x_i^1} = \frac{\|x^*\|_t - \|x^1\|_t}{\|x^2\|_t - \|x^1\|_t}. \tag{7}$$

Hence

$$x_i^* = x_i^1 + \left(\frac{\|x^*\|_t - \|x^*\|_1}{\|x^2\|_t - \|x^1\|_t}\right)\left(x_i^2 - x_i^1\right), \tag{8}$$

for $i = 1, 2, 3$.

Suppose that we get $\|x^*\|_{12} = 0.950625$. From Table 1, $\|\mathrm{P}\|_{12} < \|x^*\|_{12} < \|\mathrm{SP}\|_{12}$. By (8), we obtain

$$\begin{cases} x_1^* = 0.5 + \left(\dfrac{0.950625 - 0.708333}{0.975 - 0.708333}\right)(0.7 - 0.5) = 0.681719, \\ x_2^* = 0.7 + \left(\dfrac{0.950625 - 0.708333}{0.975 - 0.708333}\right)(1.0 - 0.7) = 0.972578, \\ x_3^* = 1.0 + \left(\dfrac{0.950625 - 0.708333}{0.975 - 0.708333}\right)(1.0 - 1.0) = 1.000000. \end{cases} \tag{9}$$

Therefore, $x^* = (0.681719, 0.972578, 1.000000)$.

3. Materials and Methods

The traditional MCDM in Figure 2 consists of five steps. Step 1: problem situation, step 2: assign weight, step 3: assign rating, step 4: aggregating ratings, and step 5: ranking.

3.1. Problem Situation and Data Collection. In the generalized decision-making of selecting offered choices, we suppose that there are p ways and the suitability indicators possessed q criteria. The evaluations of r decision-makers consisted of 2 parts: (1) importance of criteria and (2) possibility of the choices in each criteria. Both evaluations provided 2 fuzzy matrices, called weighting fuzzy matrix and rating fuzzy matrix.

Let S be a set of rating scales in Table 1. For $i = 1, 2, \ldots, q$ and $j = 1, 2, \ldots, r$, the weighting fuzzy matrix could be written as $W = [w_{ij}]$, where $w_{ij} \in S$ are the weight of i^{th} criteria, evaluated by j^{th} expert. The rating fuzzy matrix $R = [R_{ij}]$, for $i = 1, 2, \ldots, p$ and $j = 1, 2, \ldots, q$. Note that $R_{ij} \in S$ are the rating of the choices, evaluated by decision-makers. Here, we see that R is a $p \times q$ matrix and W is a $q \times r$ matrix.

3.2. Application on FMCDM. The final rating F in traditional FMCDM for $i = 1, 2, \ldots, p$ is computed as follows:

$$\begin{aligned} F = [F_i] &= \frac{1}{q}\sum_{j=1}^{q} R_{ij}\overline{W}_j = \frac{1}{q}\sum_{j=1}^{q} R_{ij}\left(\frac{1}{r}\sum_{k=1}^{r} w_{jk}\right) \\ &= \frac{1}{qr}\sum_{k=1}^{r}\sum_{j=1}^{q} R_{ij} w_{jk}. \end{aligned} \tag{10}$$

Then, we apply total utility function to the fuzzy set $\{F_1, F_2, \ldots, F_p\}$. Consequently, the ranking of the choices would be obtained. Now, we will apply our method on FMCDM. Let $[\|W\|_t]$ be matrix of $\|\odot\|_t$ of each element in W, that is, $[\|W\|_t] = [\|w_{ij}\|_t]_{ij}$. Likewise, $[\|R\|_t] = [\|R_{ij}\|_t]_{ij}$. Consider F_t by the implication of laws (10) and (5):

$$[\|F\|_t] = \frac{1}{q}\left\|\sum_{j=1}^{q} R_{ij}\overline{W}_j\right\|_t = \frac{1}{qr}\left\|\sum_{k=1}^{r}\sum_{j=1}^{q} R_{ij} w_{jk}\right\|_t. \tag{11}$$

Applying (4) and then approximating with (5), we get

$$\begin{aligned} [\|F\|_t] &= \frac{1}{qr}\left\|\sum_{j=1}^{q} R_{ij} w_{jk}\right\|_t \approx \frac{1}{qr}\left(\sum_{k=1}^{r}\sum_{j=1}^{q}\left\|R_{ij}\right\|_{tij}\left\|w_{jk}\right\|_{tjk}\right) \\ &= \frac{1}{r}\sum_{k=1}^{r}[\|R\|_t][\|W\|_t]_{ik}. \end{aligned} \tag{12}$$

Finally, we apply defuzzification to $[F_t]$. The final rating fuzzy matrix for indicating total utility of each choice is obtained. The procedure of computation is represented Figure 3.

3.3. Ordering the Optimal Intercrop Rubber Tree Plantations. Next, we will demonstrate the implementation and illustrate a case study in Phang-Nga province, Thailand.

Step 1. Problem situation: in a case study of ordering intercrop rubber tree, 3 experts were required ($r = 3$); all experts are professionals in the agricultural society

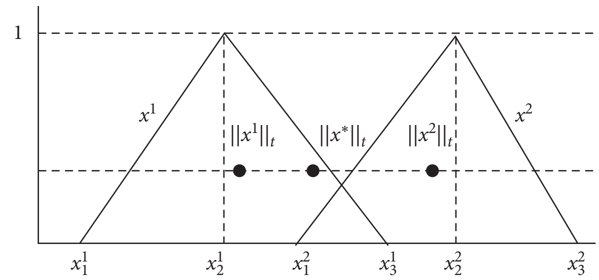

Figure 1: Geometric representation of TFNs and their shapes.

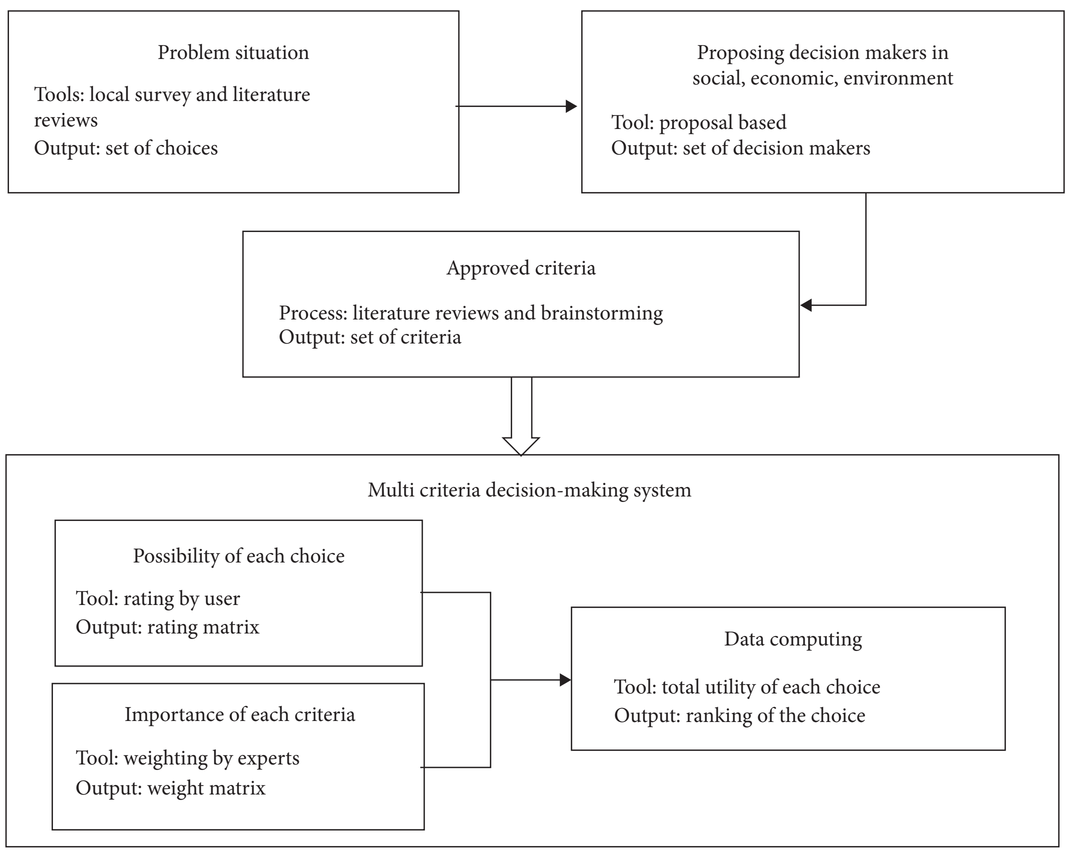

Figure 2: Framework of decision-making process.

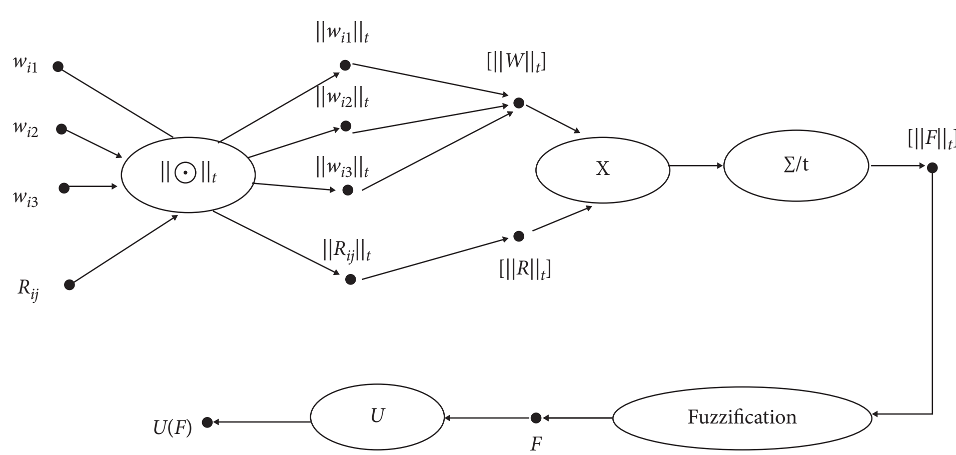

Figure 3: Computational network of FMCDM.

Table 3: List of criteria of the decision-making process.

Criteria	
Social	Meaning
C01	Cropping
C02	Harvesting
C03	Marketing
C04	Knowledge management
C05	Collective farming
C06	Government support
Economic	
C07	Investment
C08	Low cost
C09	Return
C10	Market need
C11	Noncompetition market
C12	Low price risk
C13	Low production risk
Environment	
C14	Primary soil nutrient
C15	Secondary and microsoil nutrient
C16	Bulk density of soil
C17	Soil texture
C18	Soil PH
C19	Soil temperature
C20	Light intensity
C21	Rain
C22	Wetland
C23	Temperature
C24	Stable climate
C25	Landscape

Table 4: Linguistic terms of experts' viewpoint in social criteria.

	D1	D2	D3
C01	OI	VI	OI
C02	VI	I	VI
C03	VI	I	VI
C04	I	OI	OI
C05	VI	OI	I
C06	VI	OI	I

(D1), agricultural economics (D2), and agricultural environment (D3). The selected plants consisted of 5 choices ($p = 5$) including Robusta coffee (A1), Baegu (A2), Manpu (A3), Chaya (A4), and White Turmeric (A5). A total of 25 criteria ($q = 25$) [17–21] were categorized into 3 including social, economic, and environment viewpoints (Table 3).

Step 2. Data collections and their visualizations

Step 2.1. Weighting criteria by the experts: we assign weighting criteria to the experts, and the levels of importance of each criterion are shown in Tables 4–6, associated with social, economic, and environmental viewpoints, respectively.

By applying results in Table 1, the above data represent visualization, as shown in Table 7.

Step 2.2 . Rating scales by rubber farmers: we assign rating scales evaluation of each plant under all criteria to the farmer, and the results are shown in Tables 8–10. The visualization in Table 11 shows the possibility of cropping under the each criteria.

Table 5: Linguistic terms of expert' viewpoint in economic criteria.

	D1	D2	D3
C07	LI	I	OI
C08	LI	I	LI
C09	VI	I	I
C10	VI	VI	VI
C11	NI	I	NI
C12	I	I	OI
C13	LI	I	LI

Table 6: Linguistic terms of experts' viewpoint in environmental criteria.

	D1	D2	D3
C14	VI	VI	VI
C15	OI	OI	LI
C16	NI	I	NI
C17	NI	LI	LI
C18	I	OI	OI
C19	NI	NI	LI
C20	I	I	I
C21	I	I	VI
C22	NI	NI	NI
C23	NI	NI	NI
C24	NI	NI	LI
C25	VI	LI	LI

Step 3. Final rating: the final defuzzification score in Table 12 is computed by using (12)

Step 4. Ranking: finally, the fuzziness was taken as the average of the defuzzification score of each plant in Table 12 by fuzzy rule (4). The ranking is obtained by indicating fuzzification of each plant with the total utility function. The results of this step are shown in Table 13.

In a case study, Tables 7, 11, 12, and 13 presented useful information for analysis and providing recommendations. The visualization of weighting by the experts in Table 7 showed that the environmental factor was found to be less important compared with other factors, as shown in the intensity of colouring. It was satisfying based on the fact that Phang-Nga province could be regarded as an agricultural land. The cons of the rubber farmer was demonstrated in Table 11. It is said that the rubber farmer felts concerned and lacked of confidence on agricultural economics of all plants except for Robusta coffee. However, in terms of social agriculture, agriculture practices and management of Robusta coffee were found to be problematic. According to the relationship of plant options and criteria represented in Table 12, (row views), interesting results in terms of economic viewpoints were found in Robusta coffee and chaya, whilst other plants were found to be interesting in social agriculture viewpoints. On column views, the best plant option in terms of social, economic, and environmental criteria is Baegu. And lastly, the table provides results on ranking of suitable plant options for the rubber farmer.

Table 7: Visualization of weighting by experts.

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1																									
2																									
3																									

Table 8: Linguistic terms of the decision-maker's viewpoint in social criteria.

	A1	A2	A3	A4	A5
C01	IP	P	P	IP	P
C02	IP	P	SP	WP	SP
C03	P	SP	P	WP	OP
C04	OP	P	P	WP	P
C05	P	WP	IP	IP	WP
C06	WP	OP	WP	IP	WP

Table 9: Linguistic terms of decision-maker's viewpoint in economic criteria.

	A1	A2	A3	A4	A5
C07	P	WP	IP	IP	IP
C08	P	WP	IP	WP	IP
C09	P	SP	SP	P	OP
C10	SP	SP	OP	IP	IP
C11	IP	IP	OP	WP	IP
C12	WP	P	P	P	OP
C13	OP	IP	WP	OP	OP

Table 10: Linguistic terms of decision-maker's viewpoint in environment criteria.

	A1	A2	A3	A4	A5
C14	P	SP	SP	P	P
C15	OP	P	P	P	OP
C16	SP	SP	SP	SP	SP
C17	P	SP	SP	SP	OP
C18	P	P	P	P	P
C19	OP	OP	OP	OP	OP
C20	P	OP	OP	P	P
C21	OP	P	P	OP	OP
C22	P	P	P	P	P
C23	OP	P	P	OP	OP
C24	OP	SP	SP	OP	WP
C25	OP	SP	P	OP	OP

Table 11: Visualization of decision-maker ratings.

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1																									
2																									
3																									
4																									
5																									

Table 12: Defuzzification score.

	D1	D2	D3
A1	0.293889	0.303083	0.274792
A2	0.383367	0.362844	0.350381
A3	0.333281	0.337611	0.310428
A4	0.211708	0.234089	0.196422
A5	0.2705	0.268169	0.244458

Table 13: Ranking process.

Choices	Average defuzzified value	Fuzzification			Total utility	Ranking
		Lower	Core	Upper		
A1	0.290588	0	0.298786	0.499191	0.474425	3
A2	0.365531	0.070909	0.370909	0.606364	0.564765	1
A3	0.327106	0.034022	0.334022	0.551033	0.518884	2
A4	0.214073	0	0.212707	0.441805	0.394254	5
A5	0.261043	0	0.265548	0.477032	0.443918	4

4. Conclusions

The decision-making system for intercrop selection in the rubber field was investigated in particular for the rubber famer in the area. According to general information of experts admitted in the system, all of them resided in the local area. In the analysis, the experts verified area-based criteria based on social, economic, and environmental viewpoints and evaluated the level of importance of each criterion. Next, the rubber farmers listed plants based on interests and evaluated the possibility of each plant in each criterion. The results of the system were reported to be suitable for individuals; the input data were quite vague represented in forms of five fuzzy rating scales and defuzzified by fuzzy norm. Our mathematical objects were transformed from fuzzy space to real space. Moreover, the data of weighting criteria (importance) and rating alternative plants (possibility) could be visualized by colouring defuzzified values. Finally, we used the fuzzification technique and applied total utility function. The ranking of the plants was determined to support the farmer's decision-making. Hence, the complexity of computation was reduced by the defuzzification-fuzzification technique.

By the implementation of the results of from our decision-making system for problem-solving in ordering the optimal intercrop rubber tree plantations under social, economic,, and environment criteria in Klongkean, Phang-Nga province, Thailand, we get the ranking as follows: Baegu, Manpu, Robusta coffee, White Turmeric, and Chaya, respectively. The decision-maker (rubber farmer) agrees to the results based on the popularity of Baegu and Manpu in local area. However, Baegu was found to possess more advantages compared with Manpu in terms of commercials. Chaya was seen as a new plant for the farmer in the local area. Some farmers might find this plant interesting, but the lack of knowledge in farm management and marketing caused Chaya to be considered as the worst choice. On the whole, not only do the rubber farmer gains benefit from the decision-making system but also government agencies and local authorities. Sufficient area-based data from rubber farmers could provide information supporting further development, and development plans could literally result in sustainable rubber intercropping. By considering some limitations, it should be acknowledged that the created decision-making system could provide recommendations and resolutions for local problems and the ranking is compatible to the individual rubber farmers; it could not be generalized to all local or global rubber farmers. For further studies, it would be more beneficial to develop the decision-making software based on various platforms so that the future decision-making system could be adapted to handle with other problems occurring with individual resolutions, e.g., suitable educational program for individual students.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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