CHAPTER 5

Results and Discussion

This chapter describes descriptive analysis of sustainability criteria/indicators to review the general information on cropping systems in the study area and assessment by different methods for overall sustainability of the selected cropping systems. It elaborates on the indicators that are presented in table 4. (Chapter 4)

5.1 Soil fertility management

Use of chemical fertilizer in the cropping systems, use of organic fertilizer in the cropping system and cultivation of legume crops in the cropping systems are identified as indicator of soil fertility management for ecological sustainability.

5.1.1 Use of chemical fertilizer

Agriculture profoundly affects many ecological systems. One of the negative effects of current agricultural practices is the largest single non-point source of water pollutants including sediments, salts, fertilizers (nitrates and phosphorus), pesticides and manures.

Moreover, potential health hazards are tied to sub-therapeutic use of antibiotics in animal production and pesticide and nitrate contamination of water and food. Farm workers are poisoned in fields, toxic residues are found on foods and certain human and animal diseases have developed resistance to currently used antibiotics.

So, in this study, average chemical fertilizer usage of farmers in the cropping systems was measured as an indicator of soil fertility management. Almost all farmers were applying chemical fertilizers to their farmlands. The highest amount 111.4 kg/ha was found in R-R system and the lowest amount 72.7 kg/ha was found in S-R-L system (Figure 13.).

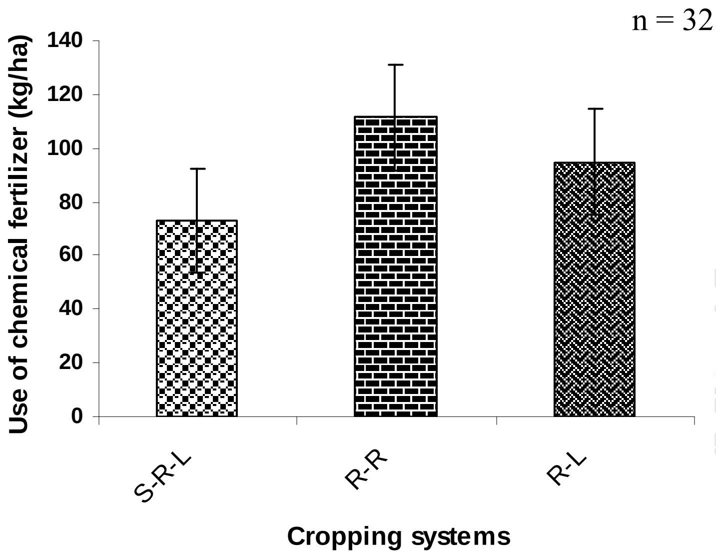

Figure 13. Average chemical fertilizers usage of farmers in the cropping systems

Source: Field survey, 2005

Notes: S-R-L = sesame-rice-legume system

R-R = rice-summer rice system

R-L = rice-legume system

Moreover, farmers in the system were not applying fertilizers in a balanced way. Most farmers use only urea in the rice field. Such imbalanced use of chemical fertilizers leads to depletion of N, K and S and accelerates soil acidity (Conway, 1990, Sattar and Mian, 1999). Discussions with farmers revealed that farmers can not apply large amount of chemical fertilizers over successive years to maintain yields because the price of chemical fertilizer is increasing compare with the price of rice within the study area (Table 6).

Table 6. Price comparison of rice and fertilizer (2004-2005)

Farm gate price of rice (kyat/basket)	Market price of chemical fertilizers (kyat/kg)
150	280(Urea) 240 (T super) 240 (Compound)

Note: 1 basket = 20.8 kg, 1 US $ = 900 kyats (2004-2005)

Source: Field survey, 2005

5.1.2 Use of organic fertilizer

The sustainability concept has prompted much discussion and need to propose major adjustments in conventional agriculture to make it more environmentally, socially and economically viable and compatible. Several possible solutions to the environmental problems created by capital and technology intensive farming systems have been proposed and research is currently in progress to evaluate alternative systems (Gliessman, 1998). The main focus lies on the reduction or elimination of agro-chemical inputs through changes in management to assure adequate plant nutrition and plant protection through organic nutrient sources and integrated pest management, respectively (Altieri, 1987). The approximate nutrient composition of the range of organic materials now used as manures is given in Table 7.

Because of the importance of organic fertilizers in replacement of agrochemical inputs, use of organic fertilizer in farming practices in the cropping systems is observed as an indicator of ecological sustainability. Kanazawa (1984) gives a maximum rate for Japan from 3-10 t/ha. Qi-xio Wen (1984) estimated that in China it averaged 2-7 t/ha in 1979. At that time organic manures were used in conjunction with inorganic fertilizers, and it may safely be assumed that rates at which organic manures were applied in the past would have been somewhat higher.

Table 7. Macronutrient composition of some organic wastes, amounts of nutrient added to soils when 2 t/ha of organic wastes are applied.

Manure	Composition (%)			Nutrient content of 2 t/ha		
	N	P	K	N	P	K
Green manures	2.7	0.2	0.3	20	4	6
Soybean cake				7	3	5
Cotton seed meal	6.6	1.1	1.2	132	22	24
Soybean meal	7	0.5	1.3	140	10	26
Farmyard manure	0.6	0.1	0.5	12	2	10
Pig manure	1.0	0.3	0.7	20	6	14
Poultry manure	1.6	0.5	0.8	32	10	16
Cattle feaces	0.3	0.1	0.1	6	2	2

Source: Greenland, 1997

In Myanmar, decreasing soil fertility has been the major concern for agricultural sustainability. Traditionally, farmers used to apply farmyard manure (FYM) and mulch crop residues to land to enhance soil fertility. Moreover, EM (Effective Microorganism) has been introduced since 1993 and Biocompozer fertilizer (produced from EM with crop residues) has been distributed by Myanmar Agriculture Service in almost agricultural area. The highest amount of 3.3 ton/ha was found in R-L system and the lowest amount of 0.7 ton/ha was found in R-R system (Figure 14).

Farmers have local knowledge to maintain nutrient cycling by organic fertilizers such as FYM, Green manure, crop residues from sesame, legume and rice, compost, Bokashi (EM+ compost) applying to the soil before and after cropping seasons since chemicals are expensive as compared to the price of rice. But in cash crops such as food legumes and vegetables they use foliar fertilizers such as biosuper, cormet as top dressing.

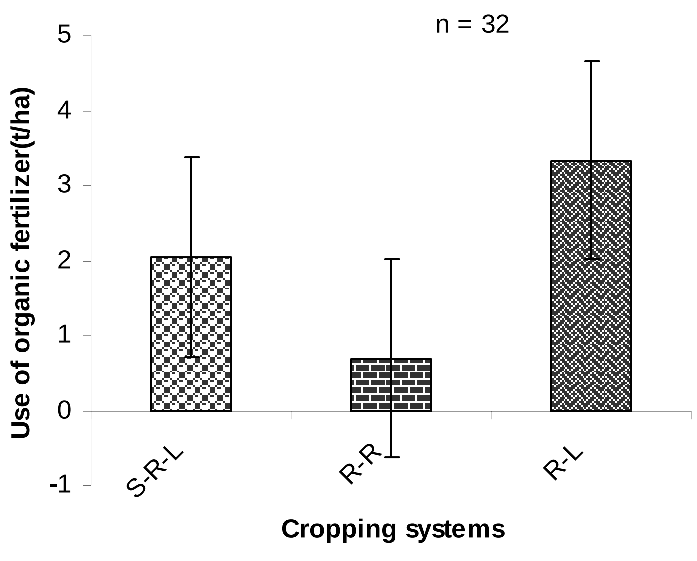

Figure 14. Average organic fertilizers usage of farmers in the cropping systems
Source: Field survey, 2005

5.1.3 Cultivation of legume crops

According to Greenland, (1997), the amount of fixed nitrogen was between 20-120 kg/ha by grain legumes grown before or after the rice crop in rice-based cropping systems. So, cultivation of legume crops is considered as one of the sources for nutrient addition from biological nitrogen fixation in the cropping systems, so that it is used as an indicator for ecological sustainability.

In Myanmar most of the farmers grow legume after rice for soil fertility management and for cash. Moreover, residue from legumes can be used as fodder for farm animals. The highest average legume cultivation of 2.6 ha/farm was found in S-R-L system and the lowest legume cultivation of 0.6 ha/farm was found in R-R system (Figure 15).

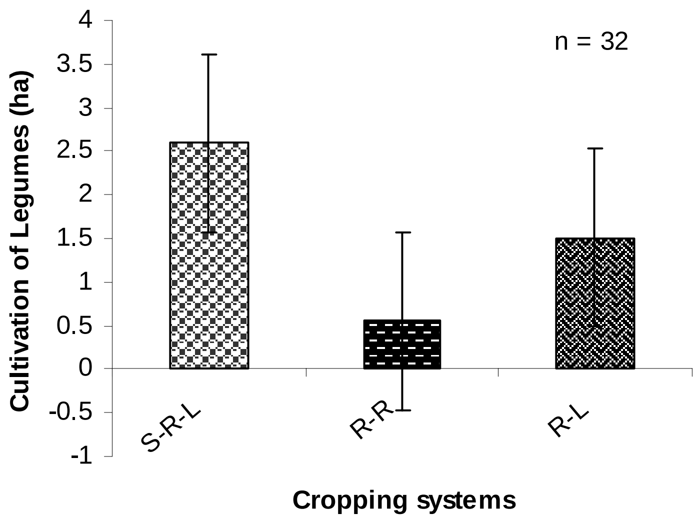

Figure 15. Average cultivation of legumes of farmers in the cropping systems
Source: Field survey, 2005

5.2 Pest and disease management

Presently, sustainable farming practices commonly include pest control strategies that are not harmful to natural systems, farmers, their neighbors or consumers. This includes integrated pest management techniques that reduce the need for pesticides by practices such as scouting, use of resistant cultivars, timing of planting and biological pest controls and use of natural or synthetic inputs in a way that poses no significant hazard to man-animals or the environment.

Management practices of farmers by chemical control are used as an indicator of ecological sustainability for the cropping systems. In this study, proportion of farmers using chemical control for cultivated crops in the cropping systems were interviewed and calculated as an indicator for sustainability. 79% of farmers from S-R-L were using chemical control and 65% of farmers from R-L, 42% from R-R system (Figure 16).

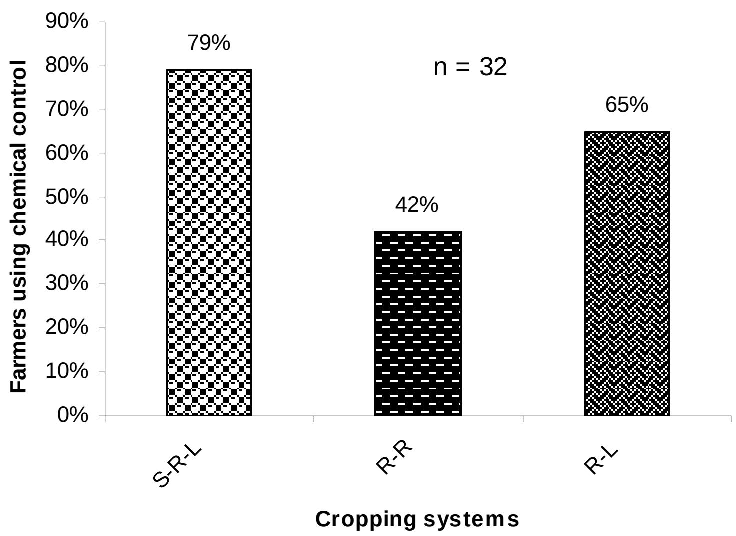

Figure 16. Proportion of farmers using chemical control in the cropping systems
Source: Field survey, 2005

5.3 Land productivity

Land productivity is measured through grain yield of rainy season rice from the cropping systems. Rice yield data were collected through field survey. The highest rice yield 3,322 kg/ha was in S-R-L and lowest 2,997 kg/ha was in R-L system (Figure 17).

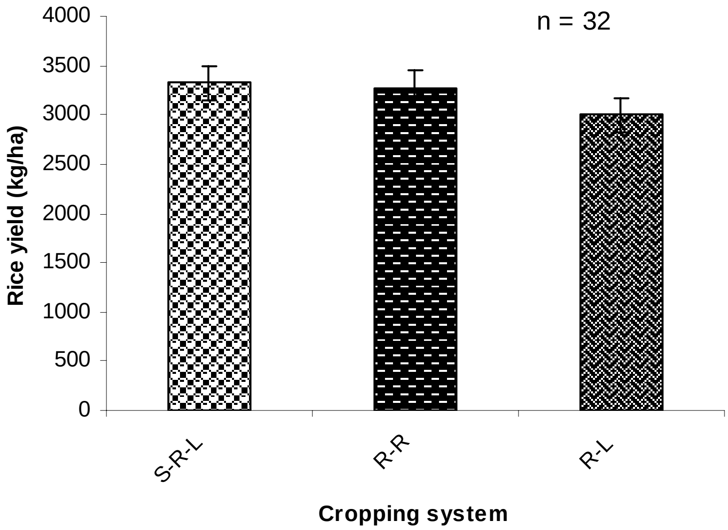

Figure 17. Average rice yield (kg/ha) in the cropping systems
Source: Field survey, 2005

5.4 Yield stability

Yield stability can be chosen as an indicator for economic viability of a system. A stable system or activity is not necessarily superior to an unstable one. Depending on relative costs/prices, an unstable activity may still be preferable to a stable one on grounds of long-run relative profit. But, other things being equal, stability will usually be chosen over instability, especially in subsistence situations where the goal is food rather than money (Mc Connel and Dillion, 1997).

In this study yield stability is measured by the Index of Trend of Yield (ITY), calculated by the equation 1. The results are presented in Table 8. In S-R-L system ITY is 0.029 and it indicates the trend of yield is a little bit increasing. Both in R-R and R-L systems, ITY is -0.375 and -0.313 and it indicates that the trend of yield is decreasing. So, comparison between the cropping systems according to yield stability, S-R-L system is preferable for sustainability than other systems.

Table 8. No. of farmers showing yield trend and Index of Trend of Yield in different cropping systems

Cropping systems	No. of farmers in increasing yield (fi)	No. of farmers in decreasing yield (fd)	No. of farmers in constant Yield (fc)	Index of trend of yield (ITY)
S-R-L	6	5	23	**0.029**
R-R	4	17	11	-0.375
R-L	3	13	16	-0.313

5.5 Profitability

According to characterization of farms by Mc Connell and Dillon, 1997, the farm type within the cropping systems is small independent specialized family farms (type 3) and part of their production is for cash income. Thus, relative importance of financial profit from the farm is more than 50 percent. So, in this study, financial profitability is used as an indicator of economic sustainability for the cropping systems since it can maintain the long term sustainability in terms of economic viability. Profitability was analyzed based on financial returns in order to understand the performance of the systems. Costs and returns were analyzed based on variable costs, including costs of human labor, animal power, seed, fertilizers, pesticides and insecticides, irrigation water, rent on power tillers, threshers and interest on operating capital. Cost of inputs were computed on the basis of market prices whether they were supplied from home or purchased. Gross return was determined based on reported crop yield and farm gate price (Kay, R. D. and W. M. Edwards, 1999). Results for profitability are presented in Table 9. Within the cropping systems, S-R-L system has highest profitability in gross revenue and gross margin. S-R-L system is 5.67 percent higher than R-R system and 44.37 percent higher than R-L system in gross revenue, but in gross margin, 41.7 percent and 44.03 percent respectively.

Table 9. Gross revenue and Gross Margin in different cropping systems

Income (kyat /ha)	S_R_L	R_R	R_L
Gross revenue	441,350	416,334	245,538
Gross margin	290,717	169,419	162,704

Note: 1 US$ = 900 kyats (2004-2005)

5.6 Input self sufficiency

Input self sufficiency is an indicator of social acceptability. Sustainable agriculture should seek to minimize the dependency on external inputs (Altieri, 2000 and Pretty, 1995). Input self-sufficiency is determined on the basis of the ratio of local inputs cost to the total inputs cost. The higher the ratio the higher is the input self-sufficiency.

There is considerable variation between the systems in terms of dependency on external inputs. In R-R system, there is a tendency to use external inputs, notably chemical fertilizers, pesticides, diesel, irrigation water and hired machine is greater accounting for 0.62% of the total input cost (Figure 18). The high dependency on external inputs increases farmer's vulnerability to reduce profit.

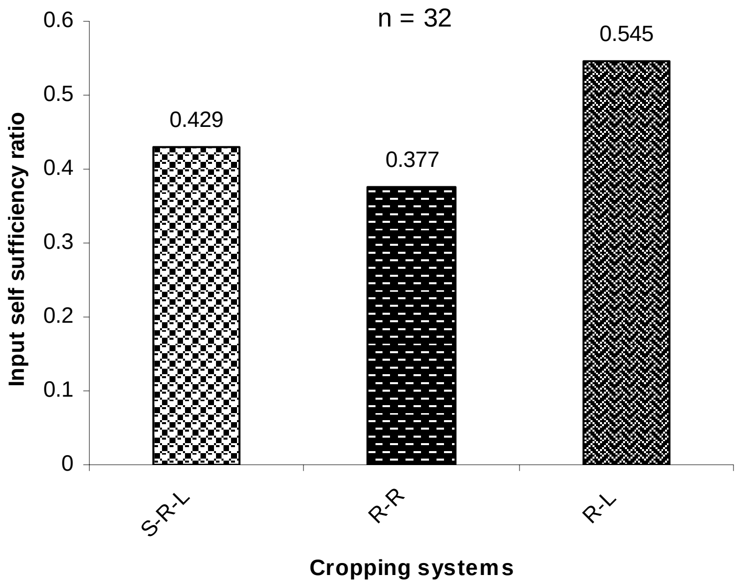

Figure 18. Input self sufficiency ratio for the cropping systems
Source: Field survey, 2005

5.7 Family food sufficiency

Food security at the farm household level, according to FAO (1997) is a matter of individual households being able to meet their daily food needs from their own production or the means to obtain food from off-farm sources. Food sufficiency has remained one of the most important in Myanmar because of limited land for agricultural use and an ever increasing population. In the cropping systems, farmers' own food grain production in the S-R-L and R-R can meet the food requirement for more than 11 months for a year and in R-L system only 9.46 months can meet the food requirement but they have ability to purchase food required for consumption (Figure 19). When we think for the requirement for the balanced diet from their own farm, S-R-L system has more ability to meet the requirement because they can get more nutrients from legumes and sesame by consuming from their farm products.

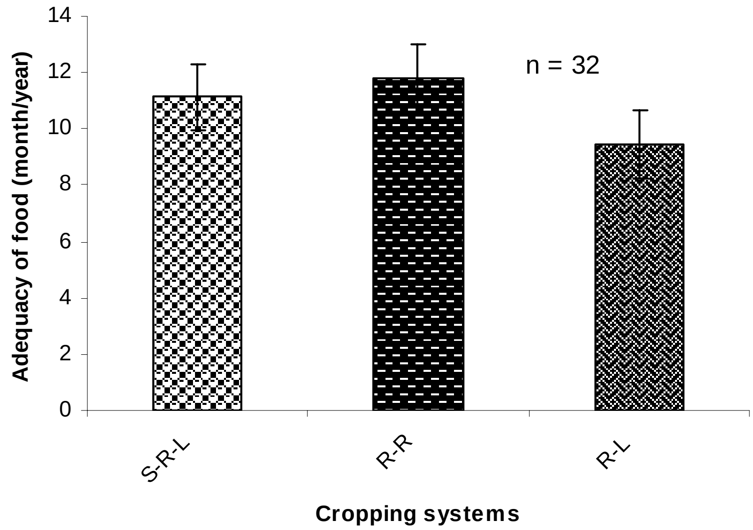

Figure 19. Family food sufficiency (months/year) for the cropping systems
Source: Field survey, 2005

Descriptive statistics analysis of sustainability indicators to review the general information on cropping systems in the study area is described in Table 10.

Table 10. Descriptive statistics of the study

CS	Variables	N	Mean	Std. Dev
S-R-L	NFM	32	5.69	2.02
R-R		32	5.88	1.81
R-L		32	5.78	1.88
	Total			
S-R-L	NFL	32	2.03	1.12
R-R		32	1.72	0.99
R-L		32	2.22	1.29
	Total			
S-R-L	TA ha	32	3.54	2.02
R-R		32	2.85	2.42
R-L		32	2.89	2.26
	Total			
S-R-L	UCF (kg/ha)	32	72.68	47.49
R-R		32	111.39	64.76
R-L		32	94.91	66.32
	Total			
S-R-L	UOF (t/ha)	32	2.04	1.95
R-R		32	0.69	0.94
R-L		32	3.33	3.59
	Total			
S-R-L	CLC (ha)	32	2.59	1.73
R-R		32	0.55	1.49
R-L		32	1.51	0.79
	Total			
S-R-L	CY	32	3,322.06	1,031.25
R-R	(Rice kg/ha)	32	3,271.68	914.4
R-L		32	2,997.05	1,009.32
	Total			
S-R-L	GM	32	290,717	206,151
R-R	(k/ha)	32	169,419	116,245
R-L		32	162,704	106,941
	Total			
S-R-L	GR (k/ha)	32	441,350	247,191
R-R		32	416,334	143,550
R-L		32	245,538	149,656
S-R-L	FFS (months)	32	11.13	1.33
R-R		32	11.78	0.75
R-L		32	9.47	2.6
	Total			

Source: Field survey, 2005

5.8 Sustainability Assessment by Fuzzy Evaluation (SAFE) method

In this study, to measure the sustainability of selected rice-based cropping systems, methodology for the Sustainability Assessment by Fuzzy Evaluation (SAFE) in Figure 8 (Chapter 4) by Andriantiatsaholiniaina and Phillis, (2000) was used to apply fuzzy logic in evaluation strategies.

5.8.1 Quantification and normalization of criteria

For quantification and normalization of criteria, nine secondary indicators (UCF, UOF, CLC, CCuse, CY, Ystab, GR, ISS, and FFS) were chosen and average values of each indicator of cropping systems were used for quantification. (Table 11)

Table 11. Quantification of criteria for selected cropping systems

Indicators	**unit**	**CS1 (S-R-L)**	**CS2 (R-R)**	**CS3 (R-L)**
1. UCF	kg/ha	72.68	111.39	94.91
2. UOF	t/ha	2.04	0.69	3.33
3. CLC	Area (ha)	2.59	0.55	1.51
4. CCuse	proportion	79%	42%	65%
5. CY	kg/ha	3,322.06	3,271.68	2,997.05
6. Ystab	Index	0.029	-0.375	-0.312
7. GR	kyats/ha	441,350	416,334	245,538
8. ISS	ratio	0.429	0.377	0.545
9. FFS	months/yr	11.13	11.78	9.47

After quantification of criteria, normalization method mentioned in section 4.6.2.1 is used to normalize the data. Normalized values of quantified data from each cropping system can be observed in table 12, 13 and 14.

Table 12 presents the minimum value (min (v)), maximum value (max (v)), threshold values for minimum and maximum (min (s) and max (s)), target value (T (v)), data value (data (v)) and normalized value (N (v)) for each indicator in Sesame-Rice-Legume system. Normalized values are constructed in 0 to 1 scale and the higher the value, the better performance in sustainability. According to normalized values in table 12, indicators UCF, CCuse and Ystab have the highest sustainability values. The second high values can be found in FFS and CLC. The medium sustainability values are GR and ISS but UOF and CY have low sustainability values.

So, the sustainability manner for each indicators reveal that, UCF, CCuse, Ystab> FFS, CLC> ISS, GR> CY, UOF.

Table 12. Normalization of sustainability indicators for the secondary variable (Sesame-Rice-Legume system)

Indicators of sustainability	**units**	**min(v)**	**max(v)**	**min (s)**	**max(s)**	**target T(v)**	**data (v)**	**N (v)**
1. UCF	kg/ha	0	245	Max	0	Min	72.68	1
2. UOF	t/ha	0	37	0	Max	Max	2.04	0.06
3. CLC	Area ha	0	3.54	0	Max	Max	2.59	0.73
4. CCuse	usage	0	100	Max	0	Min	79	1
5. CY	Kg/ha	0	15000	0	Max	Max	3322	0.22
6. YStab	Index	-1	+1	-1	+1	0	0.029	1
7. GR	Kyats/ha	0	1,076,555	0	Max	Max	441350	0.41
8. ISS	ratio	0	1	0	Max	Max	0.429	0.43
9. FFS	Months/yr	0	12	0	Max	Max	11.13	0.93

Table 13 presents the minimum value (min (v)), maximum value (max (v)), threshold values for minimum and maximum (min (s) and max (s)), target value (T (v)), data value (data (v)) and normalized value (N (v)) for each indicator in Rice-Rice system. Normalized values are constructed in 0 to 1 scale and the higher the value, the better performance in sustainability. According to normalized values in table 13, indicators UCF, CCuse and Ystab have the highest sustainability values. The second high values can be found in FFS. The medium sustainability values are GR and ISS but UOF, CLC and CY have low sustainability values.

So, the sustainability manner for each indicators reveal that, UCF, CCuse, Ystab> FFS > ISS, GR> CY, CLC, UOF.

Table 13. Normalization of sustainability indicators for the secondary variable (Rice-Rice system)

Indicators of sustainability	units	min(v)	max(v)	min (s)	max(s)	target T(v)	data (v)	N (v)
1. UCF	kg/ha	0	245	Max	0	Min	111.39	1
2. UOF	t/ha	0	37	0	Max	Max	0.69	0.02
3. CLC	Area ha	0	3.54	0	Max	Max	0.55	0.16
4. CCuse	usage	0	100	Max	0	Min	42	1
5. CY	Kg/ha	0	15,000	0	Max	Max	3,271.7	0.22
6. YStab	Index	-1	+1	-1	+1	0	-0.375	1
7. GR	Kyats/ha	0	1,076,555	0	Max	Max	416,334	0.39
8. ISS	ratio	0	1	0	Max	Max	0.377	0.38
9. FFS	Months/yr	0	12	0	Max	Max	11.78	0.98

Table 14 presents the minimum value (min (v)), maximum value (max (v)), threshold values for minimum and maximum (min (s) and max (s)), target value (T (v)), data value (data (v)) and normalized value (N (v)) for each indicator in Rice-Legume system. Normalized values are constructed in 0 to 1 scale and the higher the value, the better performance in sustainability. According to normalized values in table 14, indicators UCF, CCuse and Ystab have the highest sustainability values. The second high values can be found in FFS. The medium sustainability values are ISS and CLC but UOF,GR and CY have low sustainability values.

So, the sustainability manner for each indicators reveal that, UCF, CCuse, Ystab> FFS > ISS, CLC> GR, CY, UOF.

Table 14. Normalization of sustainability indicators for the secondary variable (Rice-Legume system)

Indicators of sustainability	units	min(v)	max(v)	min (s)	max(s)	target T(v)	data (v)	N (v)
1. UCF	kg/ha	0	245	Max	0	Min	94.91	1
2. UOF	t/ha	0	37	0	Max	Max	3.33	0.09
3. CLC	Area ha	0	3.54	0	Max	Max	1.51	0.43
4. CCuse	usage	0	100	Max	0	Min	65	1
5. CY	Kg/ha	0	15,000	0	Max	Max	2,997.05	0.2
6. YStab	Index	-1	+1	-1	+1	0	-0.312	1
7. GR	Kyats/ha	0	1,076,555	0	Max	Max	245,538	0.23
8. ISS	ratio	0	1	0	Max	Max	0.545	0.55
9. FFS	Months/yr	0	12	0	Max	Max	9.47	0.8

5.8.2 Fuzzification

For fuzzification, membership functions of the linguistic values are used to fuzzified the normalized values. For secondary variables: UCF, UOF, CLC, CCuse, CY, Ystab, GR, ISS, FFS, membership function and linguistic values are defined as follows (figure 20).

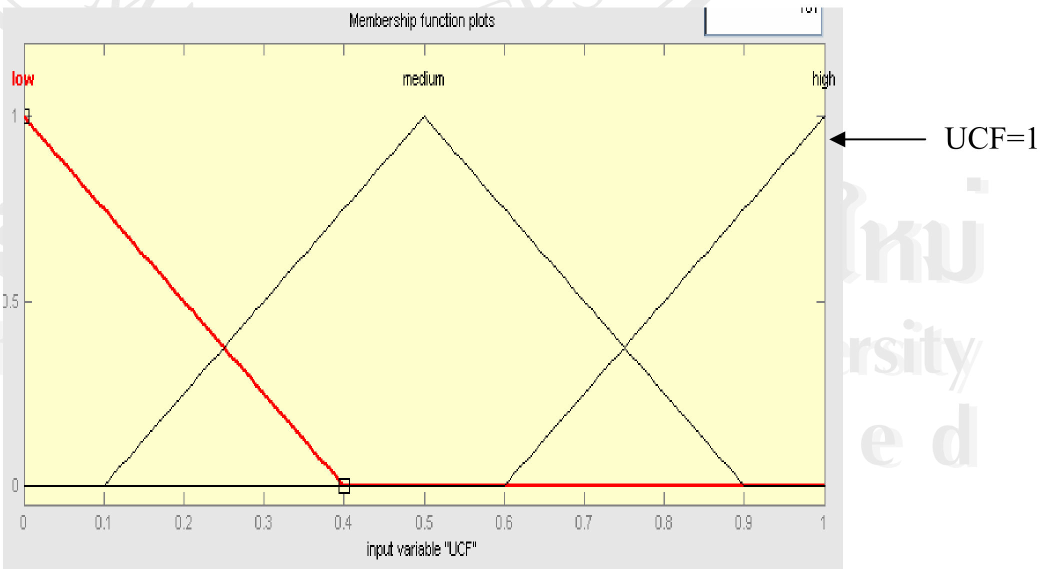

Figure 20. Membership functions for secondary variables

- MF1='low': 'trimf', [-0.4 0 0.4]
- MF2='medium': 'trimf', [0.1 0.5 0.9]
- MF3='high': 'trimf', [0.6 1 1.4]

Notes: trimf = Triangular membership function, MF = Membership Function

For example, to get the fuzzified value for UCF in S-R-L system, normalized value for UCF in S-R-L is 1, so it is identified as high (MF3, observed in figure 3), then its fuzzified values are [0.6 1 1.4]. So, for UCF, CCuse, Ystab, FFS and CLC has high (MF3), GR and ISS has medium (MF2) [0.1 0.5 0.9] and UOF and CY has low (MF1) [-0.4 0 0.4] for fuzzified values.

For primary variables: ECOLsus, ECONsus and SOCsus, and Osus, membership functions and linguistic values are as follow (figure 21).

- MF1='Vbad': 'gaussmf', [0.1062 0.00]
- MF2='Bad': 'gaussmf', [0.1062 0.25]
- MF3='Satisfactory': 'gaussmf', [0.1062 0.5]
- MF4='Good': 'gaussmf', [0.1062 0.75]
- MF5='Vgood': 'gaussmf', [0.1062 1]

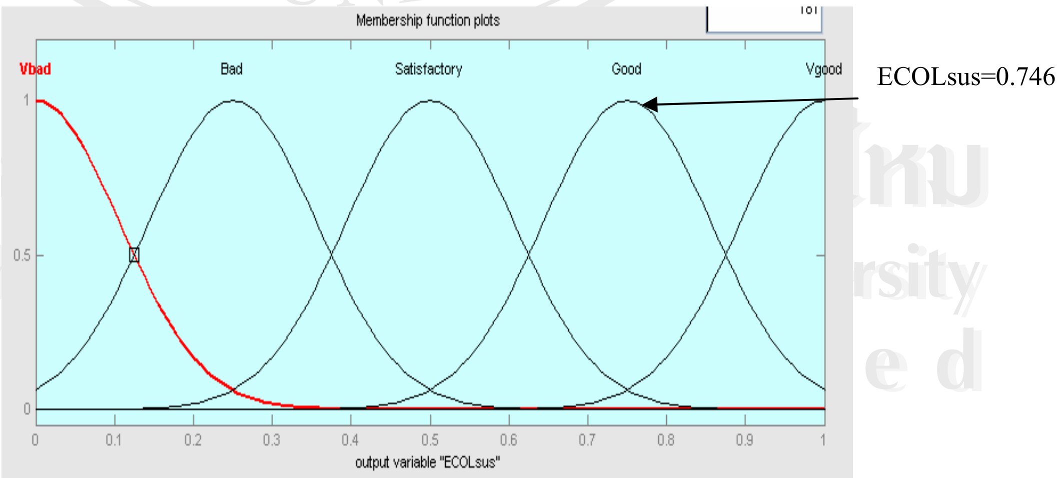

Figure 21. Membership functions for primary variables and Osus

Notes: gaussmf = Gaussian membership function

For example, the crisp value for ecological sustainability is (0.746) and can be identified as good (MF4), so fuzzified value for ECOLsus is [0.1062   0.75].

5.8.3 The linguistic rules and fuzzy operators

After fuzzification, the next step is implication of linguistic rules and fuzzy operators. In this study, knowledge acquisition methodologies are used to build the rules.

Examples of fuzzy rules are presented in Figure 22 and 23. The rule base for all aggregation steps are presented in Appendix B.

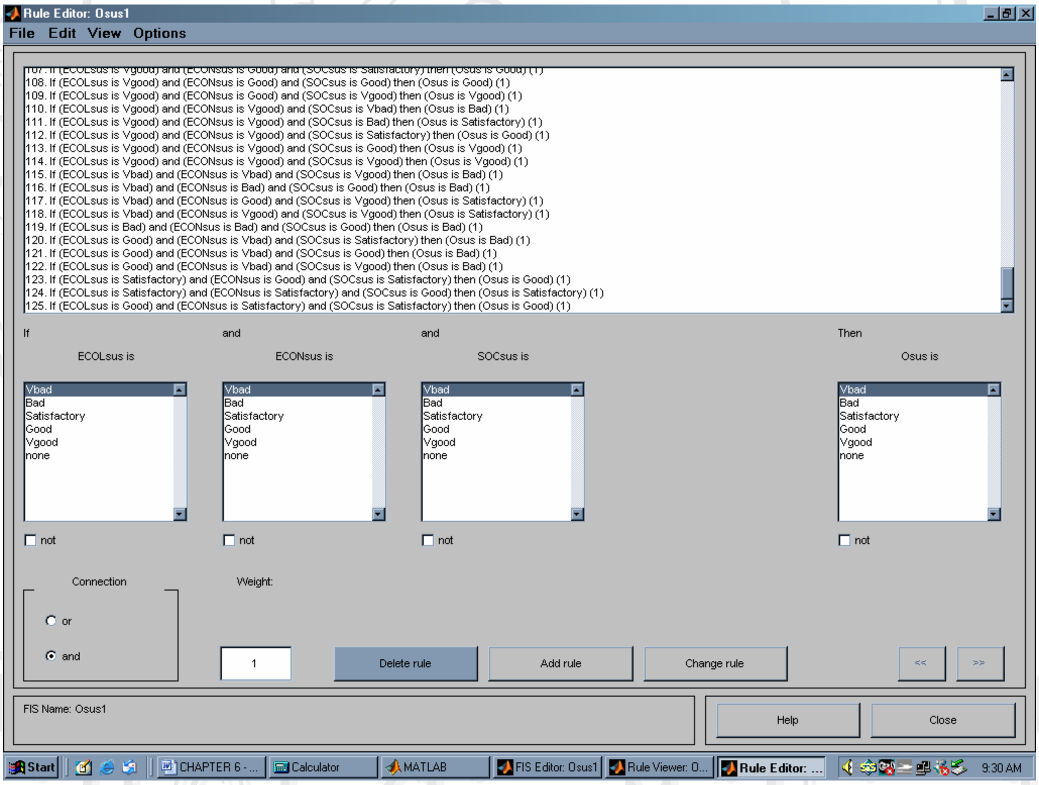

Figure 22. Implication of fuzzy rules in overall sustainability assessment

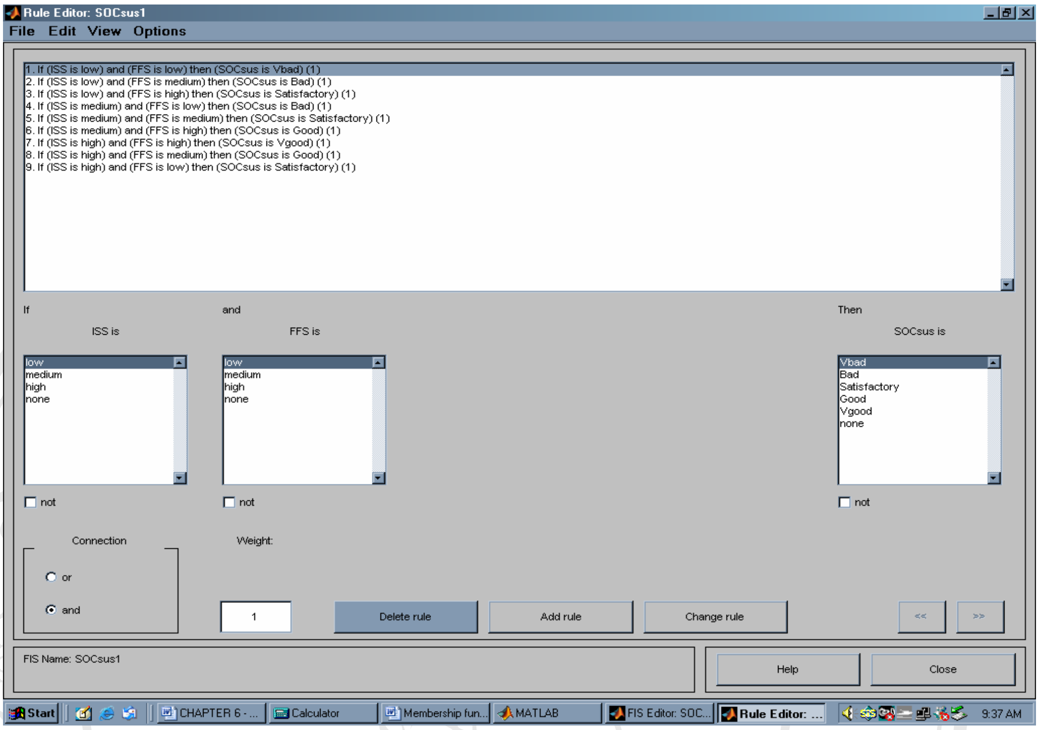

Figure 23. Implication of fuzzy rules in social sustainability assessment

5.8.4 Aggregation and Defuzzication

Defuzzification process calculates the output crisp value from the aggregated resultant fuzzy set derived after rule evaluation. In this study, center of gravity method is used for defuzzification. Final crisp value for SOCsus can be observed in figure 24.

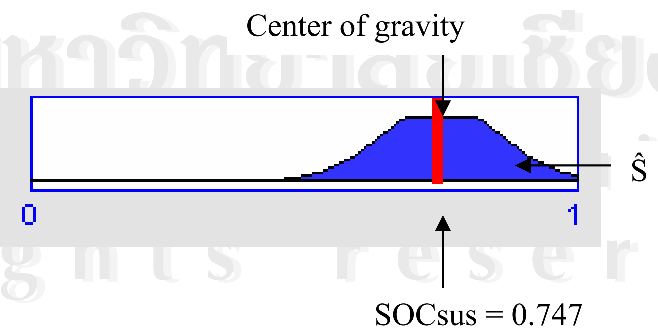

Figure 24. Graphical illustration of defuzzification of the fuzzy conclusion for social sustainability

The center of gravity method divides the area under the curve $\hat{S}$ into two equal sub-areas and thus determines SOCsus.

To assess the overall sustainability for (3) cropping systems, methodology from Figure 5 (Chapter 4) is applied with the aid of MATLAB 7.1, fuzzy logic toolbox. The final value of overall sustainability is given in the form of a percentage from 0-100. The results of overall sustainability measurement and each component for the selected cropping systems are summarized as follow (Table 15).

5.8.4.1 Sustainability in Sesame-Rice-Legume system

According to aggregation and defuzzification by SAFE method, in Sesame-Rice-Legume system, aggregate value for ecological sustainability is 0.746. So, we can identify as ‘good’ level of sustainability among five levels (VB, B, S, G, and VG) by Figure 20. We can say that ecological sustainability for this system is sustainable.

For economical sustainability, aggregate value is 0.599, so that can be identified as ‘satisfactory’ level of sustainability. In this component, crop yield is non-sustained condition but in aggregation, sustainability for economic purpose is satisfactory. In social sustainability, aggregate value is 0.747, so it can be identified as ‘good’ level of sustainability in aggregation. For overall sustainability of Sesame-Rice-Legume system, the aggregation result is 71.8% and it can be assessed as ‘good’ level of sustainability.

5.8.4.2 Sustainability in Rice-Rice system

According to aggregation and defuzzification by SAFE method, in Rice-Rice system, aggregate value for ecological sustainability is 0.553. So, we can identify as ‘satisfactory’ level of sustainability among five levels (VB, B, S, G, and VG) by Figure 20. We can say that ecological sustainability for this system is conditional sustainable.

For economical sustainability, aggregate value is 0.59, so that can be identified as ‘satisfactory’ level of sustainability. In this component, crop yield is non-sustained condition but in aggregation, sustainability for economic purpose is conditional sustainable.

In social sustainability, aggregate value is 0.726, so it can be identified as 'good' level of sustainability in aggregation. For overall sustainability of Rice-Rice system, the aggregation result is 58.3% and it can be assessed as 'satisfactory' level of sustainability.

5.8.4.3 Sustainability in Rice-Legume system

According to aggregation and defuzzification by SAFE method, in Rice-Legume system, aggregate value for ecological sustainability is 0.747. So, we can identify as 'good' level of sustainability among five levels (VB, B, S, G, and VG) by Figure 20. We can say that ecological sustainability for this system is sustainable.

For economical sustainability, aggregate value is 0.458, so that can be identified as 'satisfactory' level of sustainability. In this component, crop yield and farmers' financial revenue is non-sustained condition but in aggregation, sustainability for economic purpose is conditional sustainable.

In social sustainability, aggregate value is 0.659, so it can be identified as 'good' level of sustainability in aggregation.

For overall sustainability of Rice-Legume system, the aggregation result is 69.5% and it can be assessed as 'good' level of sustainability. The results of overall sustainability measurements are presented in Table 15.

Table 15. Overall sustainability measurement for selected cropping systems

Cropping systems	**Ecol sustainability**	**Economical sustainability**	**Social sustainability**	**Overall sustainability**	**Osus%**
S-R-L	0.746 (Good)	0.599 (Satisfactory)	0.747 (Good)	0.718 (Good)	71.8%
R-R	0.553 (Good)	0.59 (Satisfactory)	0.726 (Good)	0.583 (Satisfactory)	58.3%
R-L	0.747 (Good)	0.458 (Satisfactory)	0.659 (Good)	0.695 (Good)	69.5%

Notes: The assessment for 'Good' and 'Satisfactory' are based on figure 21.

Fuzzy evaluation involves the type of uncertainty regarding assessment of the contribution of sustainability indicators to overall sustainability. Probabilistic uncertainty relates to events that have well-defined, unambiguous meaning. Probability theory is based on classical set theory and two valued logic, e.g., true-or-false or yes-or-no statements.

Because sustainability cannot be well-defined, it is impossible to assess unambiguously whether agricultural production system is two valued: sustainable or unsustainable (Klir and Folger, 1988; Fresco and Kroonenberg; 1992). Fuzzy uncertainty, in contrast, relates to events that have no well-defined, unambiguous meaning (Kosko, 1992). Fuzzy set theory is based on multi-valued logic (McNeill and Freiberger, 1993; Pedrycz, 1993; Klir and Yuan, 1995; Zimmermann, 1996). Multi-valued logic enables intermediate assessment between strictly sustainable and strictly unsustainable; i.e., fuzziness describes the degree to which an event occurs, not whether it occurs (Kosko, 1990; Kosko, 1992).

We can conclude that overall sustainability assessment for (3) selected cropping systems for the year 2003-2004 confirms that these systems are sustainable. Since sustainability levels are given in percentages, we can easily understood. All selected cropping systems exceed 50% of overall sustainability but in Rice-Legume system, economic sustainability is less than 50%.

5.8.5 Sensitivity Analysis

SAFE model is analyzed for all 3 components using 3 different membership functions. The output from the model is shown in table 16. It is found that the absolute quantitative performances for overall sustainability vary from 0.01 to 0.04 with the confidence level, but the degree of sustainability is not changed.

Table 16. Output from sensitivity analysis with different confidence level for overall sustainability in (3) cropping systems

Cropping systems	Triangular Least confidence	Gaussian Moderate confidence	Trapezoidal Most confidence
S-R-L	0.743 (Good)	0.718 (Good)	0.75 (Good)
R-R	0.597 (Satisfactory)	0.583 (Satisfactory)	0.588 (Satisfactory)
R-L	0.653 (Good)	0.695 (Good)	0.661 (Good)

Add and subtract inputs with small fraction will be used to check the output variation by analyzing overall sustainability outcomes.The analysis of overall sustainability outcomes (S-R-L system) when input values change and the results are as follows (Table 17).

It is observed that when most important parameter CY and GR is added or subtracted fractions 0.1, the variation in overall sustainability is changing only 0.002-0.008. Adding 0.1 means 10% increase in the average value and subtracting 0.1 means 10% decrease in the average value. We can see that even though small change in Osus output, the degree of overall sustainability is not changed. So, we can conclude that the errors in input variables are insignificant for the final output.

Table 17. Sensitivity of the SAFE model with respect to input variations in Sesame-rice-legume system

Fraction change in inputs	ECOlsus Output	ECONsus Output	SOCsus Output	Osus Output
UCF (+0.1) (-0.1)	0.746 0.746	0.599 0.599	0.747 0.747	0.718 0.718
UOF (+0.1) (-0.1)	0.746 0.746	0.599 0.599	0.747 0.747	0.718 0.718
CLC (+0.1) (-0.1)	0.747 0.747	0.599 0.599	0.747 0.747	0.718 0.718
CCuse (+0.1) (-0.1)	0.746 0.746	0.599 0.599	0.747 0.747	0.718 0.718
CY (+0.1) (-0.1)	0.746 0.746	0.674 0.517	0.747 0.747	0.720 0.710
Ystab (+0.1) (-0.1)	0.746 0.746	0.599 0.599	0.747 0.747	0.718 0.718
GR (+0.1) (-0.1)	0.746 0.746	0.599 0.519	0.747 0.747	0.718 0.710
ISS (+0.1) (-0.1)	0.746 0.746	0.599 0.599	0.747 0.682	0.718 0.718
FFS (+0.1) (-0.1)	0.746 0.746	0.599 0.599	0.747 0.682	0.718 0.718

5.9 Multi-criteria Evaluation (MCE, Amoeba approach)

MCE method involves a set of alternatives that are evaluated on the basic of conflicting and incommensurate criteria. In this study, (9) indicators based on (3) principles (ecological sustainability, economic sustainability and social sustainability) are used to characterize and quantify criteria.

Following the criteria for indicators: simplification; quantification and communication, representing the sustainable notion, three major components (environment, economy and social) can be grouped as in table 4 (chapter 4). After selection of indicators, these (4) steps are followed to apply the MCE methodology.

5.9.1 Quantification of indicators

Both Fuzzy Evaluation and MCE follows the basic concepts of Multi-criteria Decision Analysis, quantification of indicators does the same idea as in table 11.

5.9.2 Normalization of criteria/ indicators

Normalization method is used the same with SAFE method and results are as follows. Normalized values are constructed in 0 to 1 scale and the higher the value, the better sustainability. So, the comparison of normalized values between cropping systems can be observed in Table 18. The results of normalized values reveals that farmers' usage of chemical fertilizers for nutrient management, farmers' usage of chemical control for plant protection and yield stability of crops are highest sustainability in all cropping systems. Farmers' cultivation of legumes in cropping systems is high sustainability in S-R-L and medium in R-L, but low sustainability in R-R system. In all cropping systems, farmers' usage of organic fertilizer for ecological sustainability and crop yields are low sustainable condition. For financial revenue for economic sustainability is medium in S-R-L system and R-R but low sustainability in R-L system. For social sustainability, family food sufficiency is high sustainability in all systems but for input self sufficiency, is medium sustainability in all selected cropping systems.

Table 18. Normalization of criteria/ indicators for selected cropping systems

Indicators of sustainability	Units	S-R-L (CS1)		R-R (CS2)		R-L (CS3)	
		Data (v)	N (v)	Data (v)	N (v)	Data (v)	N (v)
1. UCF	kg/ha	72.68	1	111.39	1	94.91	1
2. UOF	t/ha	2.04	0.06	0.69	0.02	3.33	0.09
3. CLC	Area ha	2.59	0.73	0.55	0.16	1.51	0.43
4. CCuse	usage	79	1	42	1	65	1
5. CY	Kg/ha	3,322	0.22	3,271.7	0.22	2,997.05	0.2
6. YStab	Index	0.029	1	-0.375	1	-0.312	1
7. GR	Kyats/ha	441,350	0.41	416,334	0.39	245,538	0.23
8. ISS	ratio	0.429	0.43	0.377	0.38	0.545	0.55
9. FFS	Months/yr	11.13	0.93	11.78	0.98	9.47	0.8

Notes: N (v) = normalized data value

5.9.3 Aggregation of indicators

After normalization of the data, aggregation method in section 4.6.3.3 is used to get the aggregate value for each indicator. In this calculation Wi represents the weight of each indicator and the calculation of weights are based on the reference that components of sustainability should be given identical weight in an overall sustainability assessment (IUCN/IDRC, 1995). So, equal weights (0.33) for ecological, economical and social sustainability are assigned and divided equally for secondary indicators as follows. According to calculation, 0.085 for ecological sustainability indicators (UCF, UOF, CLC and CCuse) are assigned for aggregation, 0.11 for economic sustainability indicators (CY, Ystab and GR) and 0.165 for social sustainability indicators (ISS and FFS) are assigned as weights in aggregation (Table 19).

Table 19. Calculation of weights (Wi) for indicators in overall sustainability

Components of sustainability	Weights (Wi)	Indicators	Weights (Wi)
Ecological sustainability	0.34	1. UCF	0.085
		2. UOF	0.085
		3. CLC	0.085
		4. CCuse	0.085
Economical sustainability	0.33	5. CY	0.11
		6. Ystab	0.11
		7. GR	0.11
Social sustainability	0.33	8. ISS	0.165
		9. FFS	0.165

The results from aggregation of indicators for overall sustainability for selected cropping systems are as follow.

Table 20. The results of sustainability in MCE method

Indicators	Wi	**CS1 (S-R-L)**		**CS2 (R-R)**		**CS3 (R-L)**	
		Ii	Wi*Ii	Ii	Wi*Ii	Ii	Wi*Ii
1. UCF	0.085	1	0.085	1	0.085	1	0.085
2. UOF	0.085	0.06	0.005	0.02	0.002	0.09	0.008
3. CLC	0.085	0.73	0.062	0.16	0.014	0.43	0.037
4. CCuse	0.085	1	0.085	1	0.085	1	0.085
Ecol sus			**0.237**		**0.186**		**0.214**
5. CY	0.11	0.22	0.024	0.22	0.024	0.2	0.022
6. Ystab	0.11	1	0.11	1	0.11	1	0.11
7. GR	0.11	0.41	0.045	0.39	0.043	0.23	0.023
Econ sus			**0.179**		**0.177**		**0.157**
8. ISS	0.165	0.43	0.071	0.38	0.063	0.55	0.09
9. FFS	0.165	0.93	0.153	0.98	0.162	0.8	0.132
Soc sus			**0.224**		**0.224**		**0.222**
ΣWi*Ii			**0.641**		**0.587**		**0.592**

The assessment of the sustainability can be observed both in aggregated results and comparison of all the indicators. Sustainability assessment on each indicator based on (3) components of sustainability and overall assessments for the cropping systems can be described as follows:

5.9.3.1 Sesame-Rice-Legume system

The analysis results show that the sustainability indicators in S-R-L system, UCF, CCuse and Ystab have the highest sustainability among the indicators. It reveals that farmer's usage of chemical fertilizer and usage of pesticide are in sustainable manners. Yield trends of crops in the cropping system is (+0.029) and it reveals positive yield trend and normalized value (1) means in sustainable manner for this indicator.

Second most sustainability indicator for this cropping system is CLC and FFS and normalized indices are (0.73) and (0.93). Normalized values are more than (0.5) and it means these indicators are sustainable condition in this cropping system. We can understand the fact that farmers in this cropping systems grows legumes in their farms and it can enhance the nutrient cycling system of the cropping management practices and farmers' adequacy of family food and nutrients as well.

Third most sustainable manner for this system is GR and ISS showing normalized value (0.41) and (0.43). In these indicators, normalized value (0.3- 0.5) means they are in conditional sustained condition for this system. Farmers average gross revenue for this system is (441,350 kyats /ha) and normalized value 0.41 means it is not a real sustainable condition. Input self sufficiency ratio of farmers in this cropping system is 0.43 and it reveals farmers' dependency on external inputs is about 0.57. So, this indicator can be understood as a conditional sustainability category in this cropping system.

The lowest sustainability indicators for this system are UOF and CY with normalized value (0.06) and (0.22). Normalized values are less than 0.3 and it reveals these indicators are non-sustain condition for this system. Farmers' average usage of organic fertilizer is (2.04 ton/ha) and FYM, crop residues and some organic fertilizers such as Biosuper are mainly used. But the amount of organic fertilizer usage is still low compare with sustainable farming system and should be improved in this factor. Average crop yield (rainy season rice) in this system is (3,322 kg/ha) and lower than other Asian countries so that efforts are needed to improve in this factor.

For the components of sustainability, aggregate value for ecological sustainability indicators is (0.237) and it reveals that ecological sustainability is (69.7%) performs in component sustainability (0.34). So that we can conclude ecological sustainability is sustainable condition in this cropping system. For economic sustainability, aggregate value is (0.179) and it means (54.2%) performs in (0.33), so that we can conclude sustainable condition. For social sustainability, aggregate value is (0.224) and it means (67.87%) performs in (0.33) that can be concluded as sustainable condition.

For overall sustainability, aggregate value is (0.64), then, we can conclude that the overall sustainability for this cropping system is sustainable condition.

5.9.3.2 Rice-Rice system

In R-R system, when we observed the sustainability indicators, UCF, CCuse and Ystab are highest sustainability status among the indicators. Normalized value (1) for these indicators reveals that in R-R system, farmers' chemical fertilizer usage, pesticide usage and yield stability are in sustainable condition.

The second highest sustainable indicator is FFS and its normalized value is (0.98) then, it reveals farmers' food sufficiency in this cropping system is sustainable.

The third sustainable indicators in this cropping system are GR and ISS. Their normalized values are (0.39) and (0.38); so that their sustainability is conditional sustainability category. These values reveal that farmers' financial return and input self sufficiency are conditional sustained condition and should be improved to be a sustainable manner.

The lowest sustainability indicators in this cropping system are UOF, CLC and CY. Their normalized values are (0.02), (0.16) and (0.22) so that they are non-sustained condition. It reveals farmers' organic fertilizers usage, cultivation of legumes for nutrient cycling in the cropping system and productivity of land are unsustainable condition and should be improved in this system.

For the components of sustainability, aggregate value for ecological sustainability is (0.186) and it means (54.7%) performs in component sustainability (0.34) that it is in sustainable condition. For economic sustainability, aggregate value (0.177) means (53.6%) performance in component sustainability that still sustainable condition. In social sustainability, aggregate value is (0.225) and performance is (68.1%) that sustainable condition in this component.

For overall sustainability in this system, the overall aggregate value is (0.588) and it can be concluded that the system is in sustainable condition.

5.9.3.3 Rice-Legume system

In S-R-L system, similar with the other systems, UCF, CCuse and Ystab are highest sustainable condition among the sustainability indicators. So, we can conclude that these three indicators are sustainable condition in all selected systems.

Second highest sustainability indicators are ISS and FFS in this system showing normalized value (0.55) and (0.8). Because in this system, farmers use crop residues form legume to the fields for nutrient cycling and food from legumes support farmers' requirement of nutrient balance in their daily diet. Third most sustainable manner in the indicators is CLC with normalized value (0.43). Because legumes are main cash crop for this system, it also plays important role for farmers' cash revenue and can be complement for nutrient cycling to the land for the cropping system too. But normalized value (0.3-0.5) shows that it is conditional sustain condition.

The least sustainable indicators in this system are UOF, CY and GR with normalized value (0.09, 0.2 and 0.23). It reveals that these indicators are non-sustained condition and should be improved in these factors.

To assess the sustainability of each component of the system sustainability, the aggregate values for ecological, economical and social sustainability are (0.215, 0.155 and 0.222). The performances of each component are (63.2%, 46.9% and 67.2%) in sub total. So that we can conclude economical sustainability is the weakest component among the basic components.

For overall assessment of the system, overall aggregate value (0.592) reveals that the R-L system is sustainable condition.

5.9.4 Representation and assessment of the solution

An important feature of the MCE- Amoeba approach is the representation and the assessment of each solution, once sustainability indicators have been calculated. The representation must be integration, involving all the objectives taken into account.

To fulfill our objectives, representation must be clear and easy to understand. To do so, to graphically integrate and monitor the different indicators is represented in "Amoeba or radar" diagram. The advantage of amoeba diagram is first clear and global representation of all the indicators and their associated value. Secondly, solutions can be easily compared. The results of associated value of the indicators and representation by amoeba diagram for selected cropping systems are illustrated in figure 25.

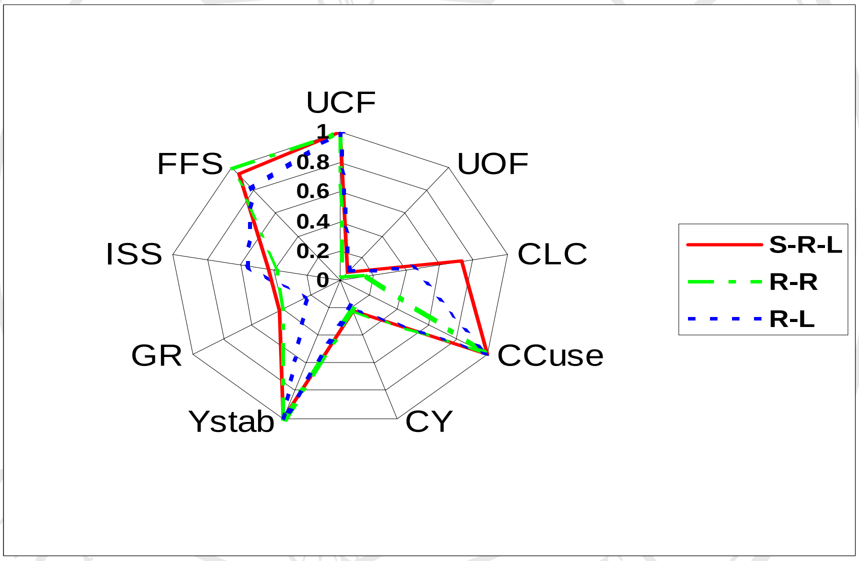

Figure 25. Representation of sustainability assessment by Amoeba diagram for selected cropping system

The assessment of overall sustainability within (3) cropping systems is easily compared by visualization; the best one is furthest to the center, the one which maximize the indicators. By reading the diagram, S-R-L system is the furthest to the center and we can conclude that it has the highest sustainability.

In this approach, solutions can be easily compared and weak area to improve will be straight visible. When we observed the diagram, UCF, CCuse, Ystab and FFS are between 0.8-1 score and it means that they are highest sustainability indicators among the cropping systems. The weak points are UOF, CY, GR showing the results between 0-0.4 score and reveals that should be improved in these indicators.

5.9.5 Sensitivity analysis

The result of sensitivity analysis for weights on (3) components of sustainability in selected cropping systems are as follow.

Table 21. Sensitivity analysis for weights on (3) components of sustainability

Combin-ation	Sustainability components	Weights	CS1		CS2		CS3	
		Wi	Ii	Wi*Ii	Ii	Wi*Ii	Ii	Wi*Ii
1	Ecol sus	0.34	0.697	0.237	0.545	0.185	0.630	0.214
	Econ sus	0.33	0.543	0.179	0.536	0.177	0.476	0.157
	Soc sus	0.33	0.680	0.224	0.680	0.224	0.675	0.223
Σ Wi*Ii		1	1.920	**0.641**	1.761	**0.587**	1.781	**0.594**
Rank				1		3		2
2	Ecol sus (+0.033)	0.373	0.697	0.260	0.545	0.203	0.630	0.235
	Econ sus (-0.033)	0.297	0.543	0.161	0.536	0.159	0.476	0.141
	Soc sus	0.33	0.680	0.224	0.680	0.224	0.675	0.223
Σ Wi*Ii		1	1.920	**0.646**	1.761	**0.587**	1.781	**0.599**
Rank				1		3		2
3	Ecol sus (-0.033)	0.307	0.697	0.214	0.545	0.167	0.630	0.193
	Econ sus (+0.033)	0.363	0.543	0.197	0.536	0.195	0.476	0.173
	Soc sus	0.33	0.680	0.224	0.680	0.224	0.675	0.223
Σ Wi*Ii		1	1.920	**0.635**	1.761	**0.586**	1.781	**0.589**
Rank				1		3		2
4	Ecol sus (+0.033)	0.373	0.697	0.260	0.545	0.203	0.630	0.235
	Econ sus	0.33	0.543	0.179	0.536	0.177	0.476	0.157
	Soc sus (-0.033)	0.297	0.680	0.202	0.680	0.202	0.675	0.200
Σ Wi*Ii		1	1.920	**0.641**	1.761	**0.582**	1.781	**0.593**
Rank				1		3		2
5	Ecol sus (-0.033)	0.307	0.697	0.214	0.545	0.167	0.630	0.193
	Econ sus	0.33	0.543	0.179	0.536	0.177	0.476	0.157
	Soc sus (+0.033)	0.363	0.680	0.247	0.680	0.247	0.675	0.245
Σ Wi*Ii		1	1.920	**0.640**	1.761	**0.591**	1.781	**0.596**
Rank				1		3		2
6	Ecol sus	0.34	0.697	0.237	0.545	0.185	0.630	0.214
	Econ sus (+0.033)	0.363	0.543	0.197	0.536	0.195	0.476	0.173
	Soc sus (-0.033)	0.297	0.680	0.202	0.680	0.202	0.675	0.200
Σ Wi*Ii		1	1.920	**0.636**	1.761	**0.582**	1.781	**0.587**
Rank				1		3		2
7	Ecol sus	0.34	0.697	0.237	0.545	0.185	0.630	0.214
	Econ sus (-0.033)	0.297	0.543	0.161	0.536	0.159	0.476	0.141
	Soc sus (+0.033)	0.363	0.680	0.247	0.680	0.247	0.675	0.245
Σ Wi*Ii		1	1.920	**0.645**	1.761	**0.591**	1.781	**0.601**
Rank				1		3		2

A sensitivity analysis involving weights consists of investigating the sensitivity of the alternatives to small changes in the value of attribute weights. If the rankings remain unaffected as the weights are varied, errors in the estimation of attribute weights can be consider insignificant (Malczewski, 1999). By imposing some perturbation on the weights, we attempted to determine the degree to which output of the weighting procedure will change. Accordingly, 10% change in (3) components of sustainability (± 0.033) perturbation on the weights is imposed and this is carried through the aggregation procedure. The results indicate that final ranking of sustainability for (3) cropping systems are stable. So that we can conclude the errors in components weight can be considered insignificant.

5.10 Sustainability Indicator Analysis (SIA) method

Sustainability indicator analysis (SIA) method assumed all sustainable indicators are equal importance. According to this method, the value of all sustainable indicators at the households in cropping systems, sustainability index, performance value as well as performance percentage are taken into calculation.

For the first step in assessing sustainability at cropping system level, a score for each indicator is developed to reflect a reference value. Example of setting score for S-R-L system for each indicator is as follow:

Table 22. Example of setting score from sampling household's data in Sesame-Rice-Legume system

Farm households	UCF	UOF	CLC	CCuse	CY	Ystab	GR	ISS	FFS
1 2 3 . . 33	C N C . . S	. .	. .	. .	. .	. .	. .	. .	S N N . . S
Total	N=3 C=10 S=20	N=33	N=6 C=1 S=26	N=29 S=4	N=33	N=10 S=23	N=15 S=18	C=9 S=24	N=11 S=22

Notes: N = nonsustained C = conditional sustained S = sustained

In this score setting, in the above example, for the indicator UCF, farmers' usage of chemical fertilizer amount greater than 163.4kg/ha is categorized as (N), 81.7-163.3 kg/ha is (C), and less than 81.7 kg/ha is (S). For all the indicators, reference values from Table 5, Chapter 4(pg 41), are used to set the score.

Second step is score computing for each indicator for the cropping systems. This computing follows those recommended by FAO sustainable land management evaluation, which DLD (1998) has applied. The results of sustainability score for selected cropping system are presented in table 23, 24 and 25. For calculation, each sustainability class is given a specific coefficient: N with 0.2, C with 0.4, and S with 0.8 (DLD, 1998). The sustainable score for each sustainability class is computed by multiplying the given coefficient with the number of samples in the respective class. The maximum score for each indicator is obtained from the maximum coefficient, 0.8, multiplied by total samples of the cropping system.

Table 23. Computation of sustainability score for Sesame-Rice-Legume system

Sus class	Coefficient	UCF	UOF	CLC	CCuse	CY	Ystab	GR	ISS	FFS
N	0.2	3	33	6	29	33	10	15		11
C	0.4	10		1					9	
S	0.8	20		26	4		23	18	24	22
SI (%)		78.0	25.0	84.9	34.1	25.0	77.3	65.9	86.4	75.0

From this table, Sustainability Index (SI), performance values and performance percentage (PP) are calculated by equation 11 and 12 (chapter 4).

Table 24. Computation of sustainability score for Rice-Rice system

Sus class	Coefficient	UCF	UOF	CLC	CCuse	CY	Ystab	GR	ISS	FFS
N	0.2	9	33	31	14	30	21	25		3
C	0.4	10				3			15	30
S	0.8	14		2	19		11	8	18	
SI (%)		64.4	25.0	29.6	68.2	27.3	49.2	43.2	77.3	93.2

Table 25. Computation of sustainability score for Rice-Legume system

Sus class	Coefficient	UCF	UOF	CLC	CCuse	CY	Ystab	GR	ISS	FFS
N	0.2	5	31	8	21	31	16	20		21
C	0.4	14	1			1			5	
S	0.8	13		24	11		16	12	27	11
SI (%)		64.4	25.8	81.3	50.8	25.8	62.5	53.1	92.2	50.8

After computation of sustainability score, results of sustainability index and performance percentage for the cropping systems are as follows.

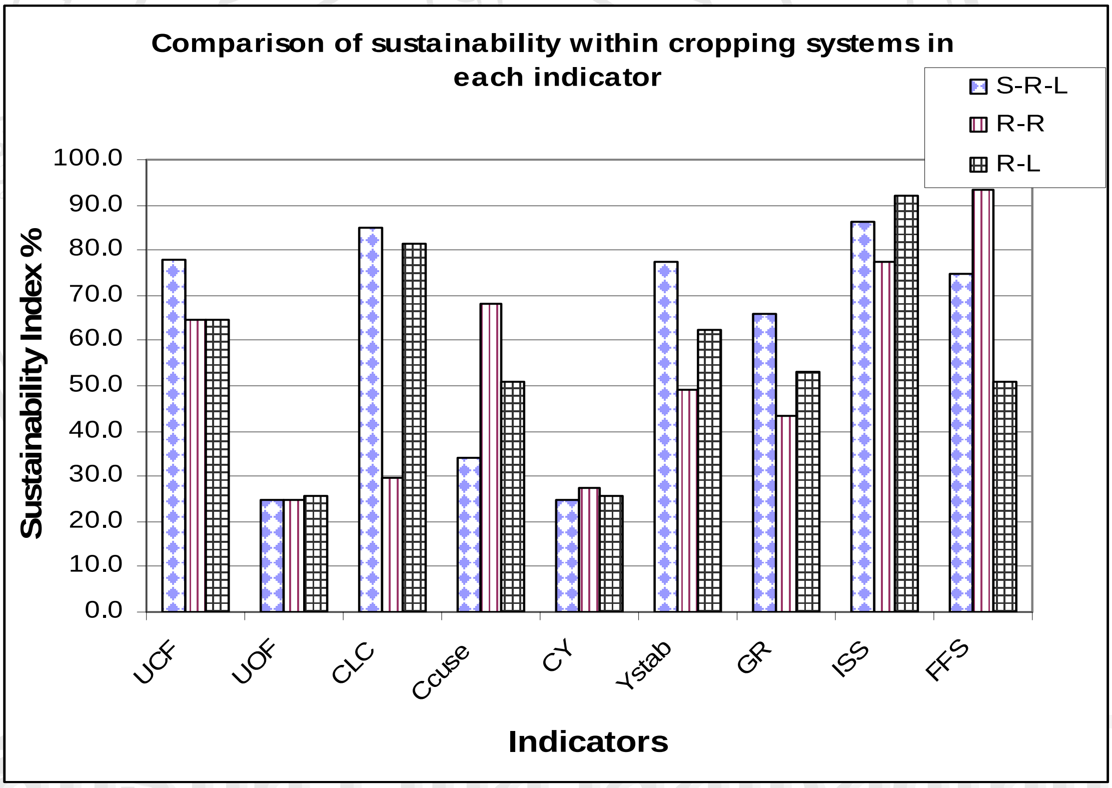

Figure 26. Comparison of sustainability within cropping systems

Table 26. Comparison of Performance Percentage for (3) cropping systems

Cropping systems		Performance Percentage (PP)	Rank
1.	S-R-L	61.28 %	1
2.	R-R	53.03 %	3
3.	R-L	56.51 %	2

According to the results, UCF, CLC, CCuse, Ystab, GR, ISS and FFS are high sustainability among the indicators. It reveals that among the management practices of the cropping systems, farmers' usage of chemicals, cultivation of legumes in the cropping systems, yield stability, farmers' financial return, input self sufficiency and family food sufficiency are sustainable condition in the cropping systems.

Among the sustainability indicators, UOF and CY are lowest sustainability compare with the others. So, we can conclude that the weakness management practices of cropping systems are usage of organic fertilizers for nutrient cycling and crop yield as non-sustained condition.

After observing the comparison within cropping systems by performance percentage (PP %), Sesame-Rice-Legume system can be ranked as (1) showing PP% (61.28 %), Rice-Legume system can be ranked as (2) showing PP% (56.51 %) and Rice-Rice system as ranked (3) with PP% (53.03 %). We can conclude that among the selected cropping systems, Sesame-Rice-Legume system has the highest sustainability and it is conformity with the previous evaluation methods.