CHAPTER 2

LITERATURE REVIEW

2.1 The concept of sustainable agriculture

According to McConnell (1997), sustainability is the capacity of a system to maintain its productivity/profitability at a satisfactory level over a long or indefinite time period regardless of year-to-year fluctuations (i.e., of its short-term instability. The concept involves the evaluation of farm activities and systems in terms of their (interrelated) ecological, economic, and socio-cultural sustainability over long time periods of many years.

Sustainable agriculture has been defined as the use of farming systems and practices which maintain or enhance the economic viability of agricultural production; the natural resource base; and other ecosystems which are influenced by agricultural activities (Anonym, 1997).

In addition, Bellini (2001) argued that agricultural production cannot be sustainable in economic and social sense without being sustainable in ecological sense. Rice (1999) in Tuan (2003) described the sustainability as the ability of any system to continue. In addition, sustainability is defined in terms of the producer and in terms of the environment. Sustainable coffee production means coffee producers are able to make living from coffee. Secondly, the coffee production should not negatively impact the environment.

Sustainability is a process and not an event (Hoon, 1997). Sustainability is a multidimensional concept. Lefroy (2000) mentioned that the concept of sustainability is a dynamic concept in terms of time and place, where sustainability in one area might not be the same with the other, and what have been considered sustainable at one time might not be longer sustainable in the future due to the change of condition and attitudes. In the context of farming systems, it may relate to physical, biological, economic and social attributes. Kaine and Tozer (2005) in Lien *et al*. (2007) stated that applying this notion to the choice between alternative farming systems, could specify to economic sustainability which has meaning that the ability of the system to continue into the future, and at the level of the individual farm, primarily means that the farm business must remain financially viable while providing an acceptable livelihood for the family farm.

FAO (1991) defined sustainable agriculture as management and natural resources conservation (soil, water, germ plasmas, crops and livestock) and changes of technological orientation as well as institutions to satisfy human needs at present and for future generations. TAC/CGIAR (1988) defined sustainable agriculture as the successful management of resources for agricultural farming that can help meet the ever changing human needs and to conserve or improve the quality of the environment and also to sustain natural resources.

Low input agriculture

Parr *et al* (1990) affirmed that low input farming systems can be determining the sustainability in farming systems. Low input of agriculture here means to optimize the management and use of internal production inputs (i.e. on-farm resources) and to minimize the use of production inputs (i.e. off-farm resources), such as purchased fertilizers and pesticides, wherever and whenever feasible and practicable, to lower production costs, to avoid pollution of surface and groundwater, to reduce pesticide residues in food, to reduce a farmer's overall risk, and to increase both short- and long-term farm profitability.

The term is somewhat misleading and indeed unfortunate. For some it implied that farmers should starve their crops, let the weeds choke them out, and let insects clean up what was left. In fact, the term low-input referred to purchasing few off-farm inputs (usually fertilizers and pesticides), while increasing on-farm inputs (i.e. manures, cover crops, and especially management). Thus, a more accurate term would be different input or low external input rather than low-input (Norman, 1997)

Good agricultural practices (GAP)

FAO (2003) defined GAP approach broadly as an approach which it aims at applying available knowledge to addressing environmental, economic and social sustainability dimensions for on-farm production and post-production processes, resulting in safe and quality food and non-food agricultural products. Based on generic sustainability principles, it aims at supporting locally developed optimal practices for a given production system based on a desired outcome, taking into account market demands and farmers constraints and incentives to apply practices.

However, the term "GAP" has different meanings and is used in a variety of contexts. For example, it is a recognized terminology used in international regulatory frameworks as well as in reference to private, voluntary and non-regulatory applications that are being developed and applied by governments, civil society organizations and the private sector.

Integrated farming systems (IFS)/Integrated food and farming systems (IFFS)

According to Hesterman (1994) farming research and policy programs have begun to recognize that by viewing farms and the food production system as an integrated whole, more efficient use can be made of natural, economic, and social resources. Included in this concept are the goals of finding and adopting "integrated and resource-efficient crop and livestock systems that maintain productivity, that are profitable, and that protect the environment and the personal health of farmers and their families," as well as "overcoming the barriers to adoption of more sustainable agricultural systems so these systems can serve as a foundation upon which communities will be revitalized".

2.2 Livestock and sustainability of agricultural systems

2.2.1 Role of livestock

Schiere (2002) stated that Livestock, and particularly ruminants, traditionally graze on natural pasture, forest areas, roadsides, fallow lands, crop re-growth or crop residues such as straws, bran's, oilseeds, and other by-products. When abundant feed is available, livestock can be considered a form of wealth, power and security, a perception based on the conversion of solar energy captured in biomass into products valuable for human society. Indeed, under conditions of abundant biomass, cattle were often a decisive factor in the survival (sustainability) of a system. However, ways and objectives of keeping livestock are changing as a cause and result of changing access to feed. Often, animal production is associated with problems of un-sustainability.

2.2.2 Benefits of livestock

Livestock were components of systems with long term sustainability. For example, the keeping of livestock was essential for survival in divergent systems such as those of the pastoralists in Africa, and those on peat soil pastures of the Low Countries and on mountain ranges unsuitable for cropping. Animals have long been essential in sustaining crop yields in the infield–outfield systems of Western Europe and other parts of the world, where dung and draught from wasteland grazing (outfields) was used for crop cultivation on the infields around the homesteads.

In a more intricate way, animals helped to sustain crop yields by increasing the rate of nutrient flows in the mixed crop–livestock systems of the Norfolk and the Flemish systems, or by allowing farmers to include crops that fix atmospheric nitrogen, release immobilized phosphorus, or enhance soil organic matter. Grazing by livestock usually follows rather than precedes deforestation and/or cropping. In fact, animals, such as the goat, are one of the last means of survival for large numbers of poor people on bare, exhausted, and/or arid lands.

However, in spite of the importance of animals for the poor classes of farmers, the advocates for continued animal production on exhausted soils should acknowledge that livestock can tip the final balance in delicate ecosystems (Schiere and Grasman, 1997).

2.3 Indicators of agricultural sustainability

DFID (2002) in Pretty (2006) acknowledged that the concept of agricultural sustainability has grown from an initial focus on environmental aspects to include first economic and then broader social and political dimensions, as follows:

a. *Ecological* – the core concerns are to reduce negative environmental and health externalities, to enhance and use local ecosystem resources, and preserve biodiversity. More recent concerns include broader recognition for positive environmental externalities from agriculture (including carbon capture in soils and flood protection).

b. *Economic* – economic perspectives seek to assign value to ecological assets, and also to include a longer time frame in economic analysis. They also highlight subsidies that promote the depletion of resources or unfair competition with other production systems.

c. *Social and political* – there are many concerns about the equity of technological change. At the local level, agricultural sustainability is associated with farmer participation, group action and promotion of local institutions, culture and farming communities. At the higher level, the concern is for enabling policies that target poverty reduction.

Researchers have categorized sustainability indicators into economic, social, and ecological aspects. Sustainability of agriculture in the context of development efforts has to meet production efficiency, resilience of ecosystem, appropriate technology, maintenance of the environment, cultural diversity, and satisfaction of the basic needs (Duc, 2005). In addition, there are some strong relationships between economic, social, and environmental issues, e.g. to state the obvious, many of the issues measured by social and environmental indicators have profound economic consequences (Anonym, 1997).

Smith and McDonald (1998) in Praneetvatakul, *et al.* (2001) stated that in the agricultural sector, goals for sustainability generally include the maintenance or enhancement of the natural environment, provision of human food needs, economic viability, and social welfare. Inevitably, the ability of a community to maintain sustainable agricultural activities overtime depends on the practices at the present time. In other words, for agricultural activities to be sustained, they should be technically feasible, economically viable, socially acceptable, and environmentally sound at any point in time.

Based on these attributes, Zhen (2003) proposed amounts of fertilizers and pesticides used, irrigation water used, soil nutrient content, depth to the groundwater table, water use efficiency, quality of groundwater for irrigation, and nitrate content of both groundwater and crops involved in ecological indicators. Economic indicators include crop productivity, net farm income, benefit–cost ratio of production, and per capita food grain production. Social indicators encompass food self-sufficiency, equality in food and income distribution among farmers, access to resources and support services, and farmers' knowledge and awareness of resource conservation.

Bellini (2001) assessed the ecological dimensions of sustainability which called agri-environmental on farm management practices through farm structure survey conducted in 1998. The indicators under the agri-environmental that have been used are soil and land management, irrigation technology, nutrient management, and pest management.

Anonym (1997) in the “Farm Management 500 Project Benchmarking for Sustainability Indicators” stated that there are two types of sustainability indicators. First, regional or national indicators covered net farm income, productivity, food contamination level, water use efficiency, nutrient balance, terms of trade, farm planning capacity, farmer education level, as the higher value sub indicators. Second, on-farm indicators, which included disposable income per household, property management plan, farm cost as percentage of income, debt to income ratio, soil erosion, return of assets, return of equity, equity, as the higher value sub indicators.

Rasul and Thapa (2004) used five indicators in assessing the ecological sustainability, namely land-used pattern, cropping pattern, soil fertility management, pest and disease management, and soil fertility status. In order to assess the economic viability in term of economic sustainability, they used land productivity, yield stability, and profitability. And the social acceptability was assessed in terms of input self sufficiency, equity, food security, and the risk and uncertainty in crop cultivation.

According to Lopez *et al.* (2002) sustainability can be defined by seven general attributes of Natural Resource Management Systems (NRMS): productivity, stability, reliability, resilience, adaptability, equity, and self-reliance (self-empowerment). In order to operate a consistent relationship between sustainability indicators and the general attributes of sustainable NRMS, there were six operational structure of MESMIS approach (a systemic, participatory, interdisciplinary and flexible framework for sustainability evaluation which in this paper focused mainly on local issues, from the farm plot to local villages) that were chosen, those are: (i) definition of the evaluation object, (ii) determination of the system’s critical features, (iii) selection of strategic indicators, (iv) indicator measurement and monitoring, (v) synthesis and integration of results, and (vi) conclusions and recommendations. Under the third phase, they described an example of selected the strategic indicators to evaluate the sustainability of two coffee production systems in the highlands of Chiapas, Mexico based on the above attributes, with details described in Table 2.1.

Table 2.1 Sustainability indicators of coffee production systems in Mexico

Attribute	**Diagnostic criterion**	**Strategic indicators**	**Measurement method**
Productivity	Efficiency	Yields	Sampling
		Produce quality	Random sampling to determine percent of aborted berries and defective berries
	Profitability	Marginal cost/benefit	Cost-benefit analysis
		Labour demand	Socio-economic survey
		Net income/total income	Socio-economic survey
Stability, resilience, reliability	Biological diversity	Number of managed species	Survey of floras
	Economic diversity	Income from non-coffee crops	Census of non-coffee plants and products
		Market diversification	Coffee marketing process
	Biological vulnerability	Pest incidence	Random sampling in plots
		Erosion	Measuring in runoff plots
		Nutrient balance	Soil, compost and berry analyses
	Economic vulnerability	Input availability	Technical monitoring dossier per plot
		Fluctuations in coffee prices	History of coffee prices
	Social vulnerability	Permanence of coffee producers in the systems	Majomut producers’ registry

Table 2.1 (Continued)

Attribute	**Diagnostic criterion**	**Strategic indicators**	**Measurement method**
Adaptability	Capacity for change	Producers and area cultivated per system	Majomut producers' registry
Equity	Distribution of benefits, and decision-making power	Decision-making mechanisms	Interviews with Majomut Directive Board
		Distribution of returns and benefits	Institutional survey
Self-reliance	Participation	Attendance to assemblies and other events	Institutional survey
	Training	Number of producers trained	Quantification of training courses
	Self-sufficiency	Reliance on external resources	Financial statistics of Majomut

Sources: Lopez et al. (2002)

Regarding to the sustainable indicators which are typical and different between different levels, the series of index as indicators for sustainability assessment at farm level are also discussed by Rigby *et al.* (2001). In their paper, they focused specifically on the development of an indicator of sustainable agricultural practices at the farm level for a sample of 237 UK horticultural producers. As a report based on Taylor *et al.* (1993), in Malaysia there were five indicators constructed to measure the sustainability of agricultural practices at farm level, such as: (i) insect control, (ii) disease control, (iii) weed control, (iv) soil fertility maintenance, and (v) soil erosion control. In other research, Gomez-Limon (2006) constructed a farm level indicators of sustainability used six aspects, those are: (i) yield, (ii) profit, (iii) frequency of crop failure, (iv) soil depth, (v) organic carbon, and (vi) permanent ground cover.

In addition, Kammerbauer *et al.* (2001) studied the indicators development in tropical mountainous regions and some implications for natural resource policy designs as an integrated community case study. They identified and assessed indicators of landscape mosaic, soil fertility, water resources, as well as production systems and extractive activities, economic and social performance, and institutions, both of which were produced by the local population as well as by the researchers at the community level.

2.3.1 Normalization of indicators

In order to assess the overall sustainability of a system, the difficult tasks are how to sum up and get the final value which addresses all disciplines that related with sustainability for the given system. Indicators in different criteria have different units and measurement. So, before we combine the indicators, it should be normalized. Malczewski (1999) suggested "score range procedures" to normalize the multiscale attributes. Thus,

$$x_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \qquad \ldots (1)$$

Where: x_{ij} is normalized value for *i* object and *j* attribute, x_{ij} is raw value for *i* object and *j* attribute, $x_j^{\max} - x_j^{\min}$ is range of the given criterion. The score scale is 0 – 1.

Then, it will be normalized using the formula adapted from Krajnc and Glavic (2005) as follows:

$$I_{nj} = \frac{I_{aj} - I_{\min j}}{I_{\max j} - I_{\min j}} \qquad \ldots (2)$$

Where I_{nj} is normalized indicator value, I_{aj} is raw value of the indicator, and I_{max} and I_{min} are maximum and minimum values in the sample respectively. The score scale is also from 0 – 1.

2.3.2 Aggregation of indicators

The dimensions under sustainability of a system (ecological, economic, and social) have different values and measurements. In order to aggregate all of it, the standardized and weighted performance scores should be added up along a hierarchical tree. Thus,

$$A = \sum W_i X_{ij} \quad \dots (3)$$

Where:

A = overall score

W_i = weight assigned for i^{th} attribute

X_{ij} = the score of i^{th} alternative with respect to the j^{th} attribute

2.4 Assessing sustainability in agriculture

Smith and McDonald (1998) discussed about the indicators to measure sustainability based on four scales: field, farm, watershed, and region/nation based on social, economic, and biophysical indicators which appears in Figure 2.1. Duc (2005) stated that sustainability cannot be measure per se, but rather than can be seen through the comparison of two or more systems. In his thesis, he used three widely popular techniques which are: Analytical Hierarchy Process (AHP), Sustainability Indicator Analysis (SIA), and the AMOEBA multi-dimensional reading. Pinnalanda (2007) also used AHP as decision making tool in assessing sustainability of surface and drip irrigation for banana cultivation in dry zone, Sri Lanka.

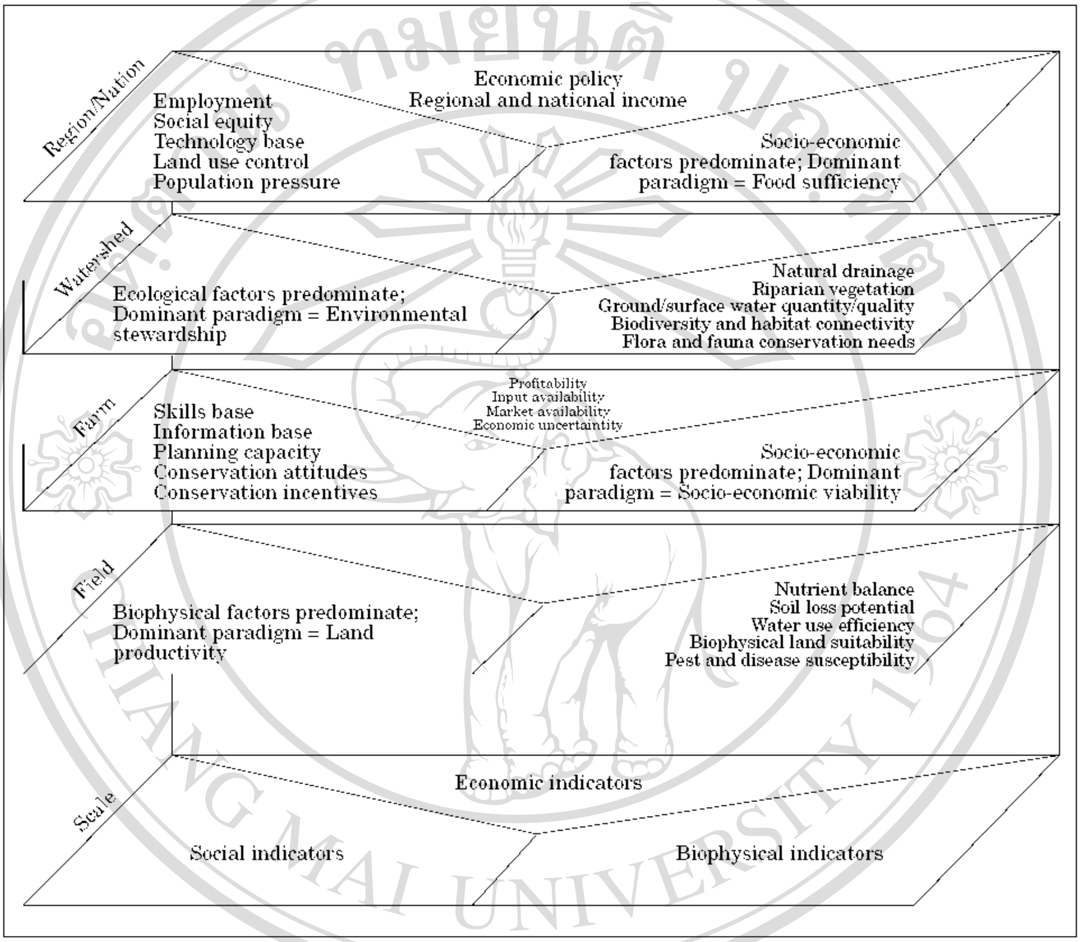

Figure 2.1 Four scales of sustainability indicators

AHP was developed to promote improved decision making for a specific class of problems that involve prioritization of potential alternate solutions through evaluation of a set of criteria elements. SIA was established based on the criteria and scoring technique was used for assessment which all indicators are assumed to have equal importance to the sustainability. AMOEBA is a tool that deals with multidimensionality to make it possible to have an overall assessment by 'radar diagram' with different parts, each describing a distinct view on the system (Duc, 2005).

Cauwenbergh, *et al.* (2007) discussing about Sustainability Assessment of Farming and Environment (SAFE) framework as a holistic, hierarchical methodology to structure information about the agro-ecosystem in order to assess its sustainability level. SAFE starts from defining sustainability as maintaining or enhancing the environmental, economic and social functions of an agro-ecosystem as formulated in a set of principles and criteria. SAFE operates at three spatial scales: the field, the farm and landscape/administrative unit.

Kammerbauer *et al.* (2001) had given their special attention to indigenous and qualitative indicators for development in a study of a typical watershed in central Honduras. Qualitative and quantitative indicators of the state of production factors and the environment could define the resource conditions. Participatory methods and interview techniques were used to draw the vision of community members regarding the problems related to natural resources management and other relevant issues that related to community development. In addition, laboratory and statistic analysis also used to explain complex development tendencies in watershed and community and to identify the implication of natural resource policy design for mountainous regions. While, spatial and temporal databases were used to assess the changes in land cover and landscape use patterns over time.

In scoring and weighting sustainability of farming practices, Rigby *et al.* (2001) assessed the impact of farming practices by identifying from the literature criteria commonly adopted, and allocating simple score to each of them with consideration whether particular practice improved or diminished a farm's performance in a certain criterion. The scoring system that they applied is in absolute terms with value 0, 0.5, 1, or 3 points for each criterion. The interpretation of those values is: 0 indicates ‘no significant impact’, 0.5 indicates ‘marginal impact’, 1.0 indicates ‘significant impact’, and 3 indicate ‘strong significant impact’. Besides using the scoring system, they also used positive (+) and negative (-) value to measure the positive impact and negative impact. Then, those scores were calculated to gain the mean, standard deviation, minimum, and maximum by using Analysis of Variance (ANOVA) in order to compare the original farming practices with the conventional one. Furthermore, as a result, those scores were combined in to AMOEBA diagram to draw clearly the relationship between indicators and their mean values for organic and conventional farms component.

Lefroy *et al.* (2000) used secondary data source from the previous study, interviews at household and village level, rapid rural appraisal, and farmer participatory techniques with selected groups of farmers in an attempt to develop indicators for sustainable land management based farmer survey in Vietnam, Indonesia, and Thailand. The information that was collected covers demography, history of the settlement and households, ethnicity and belief systems, farming systems, cropping patterns, livestock production, forest and water management, conservation strategies, tenurial status, marketing, agricultural and non-agricultural income and expenditure, road systems, education, health and nutrition, local organizations and social co-operation, internal conflicts, major problem and solutions to these problems, access to capital, and access to outside support services. Evaluation of biophysical factors included detailed descriptions of the cropping systems, including inputs, fallow periods, etc., the physical characteristics of the fields in terms of erosion, fertility status, soil water status, weed, pest and disease management, and quality of off-farm water.

2.4.1 Analytical Hierarchy Process (AHP)

AHP is a multi-criteria decision method that uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the user (Saaty, 1980). The overall objective of the decision lies at the top of the hierarchy, criteria, sub-criteria, and alternatives are on descending levels of this hierarchy.

To compute the weight of factors of n elements, the input consists of comparing each pair of the element using the following scale set:

$$s = \left[\frac{1}{9},\frac{1}{8},\frac{1}{7},\frac{1}{6},\frac{1}{5},\frac{1}{4},\frac{1}{3},\frac{1}{2},1,2,3,4,5,6,7,8,9\right] \quad A = \begin{bmatrix} a_{11} & a_{12} & . & a_{1n} \\ a_{21} & a_{22} & . & a_{2n} \\ . & . & . & . \\ a_{n1} & a_{n2} & . & a_{nn} \end{bmatrix}$$

The pairwise comparison of element *i* with element *j* is placed in the position of a_{ij} of the pairwise comparison matrix A above. The reciprocal value of this comparison is placed in the position a_{ij} of A in order to preserve consistency of judgment. Given n elements, the participating decision maker thus compares the relative importance of one element with respect to second element, using 9-point scale showed in Table 2.2.

Table 2.2 The AHP scales for paired comparisons

Intensity of importance	Definition and explanation
1[*]	Equal importance – two activities contribute equally to the objective
3	Moderate importance – experience and judgment slightly favor one activity over another
5	Essential or strong importance – experience and judgment strongly favor one activity over another
7	Demonstrated importance – an activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance – the evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments when compromise is needed
Reciprocal of above numbers	If an activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.
Rational	Ratios arising from the scale – if consistency were to be maintained by obtaining *n* numerical values to span the matrix

[*] The scale 1.1, 1.2, …, 1.9, or even a finer one, can be used to compare elements that are close together, or near equal in importance. Similarly for 2, 9.

Sources: Adapted from Saaty (1980) and Alphonce (1997)

From the preference matrix a corresponding set of weights (the eigenvector w) and a consistency ratio (CR) are determined by the AHP computer program known as “expert choice”. The consistency ratio is ratio of the decision maker’s inconsistencies and the inconsistencies obtained from randomly generated preferences. Thus,

$$CR = \frac{CI}{RI} \quad , \quad CI = \frac{\lambda_{\max} - n}{n-1} \qquad \ldots(4)$$

Where CR is consistency ratio, CI is called the consistency index, RI is random index. λ_{max} is the largest eigenvalue of the matrix A and the corresponding eigenvector *w* contains only positive entries.

Tabel 2.3 Average consistencies of random matrices

Size of the matrix	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If CR of the matrix is higher, it means that the input judgments are not consistent, and hence are not reliable. In general, a consistency ratio of 0.1 or less is considered acceptable. If the value is higher, the judgments may not be reliable and have to elicit again (Pinnalanda, 2007).

2.4.2 Sustainability indicator analysis (SIA)

In general, sustainability of agriculture in the context of development efforts has to meet: (i) production efficiency, (ii) resilience of ecosystems, (iii) appropriate technology, (iv) maintenance the environment, (v) cultural diversity, (vi) satisfaction of basic needs. Sustainability indicators were established based on the criteria and scoring technique was used for assessment. All of indicators were assumed to have equal importance in terms of their contribution to agricultural sustainability.

As a case, Praneetvatakul *et al.* (2001) employed SIA to assess the sustainability of Mae Chaem catchment in North Thailand at various levels including household, village, and sub-catchments. In the study, the scores were aggregated and used to classify the households into different sustainability classes. The sustainability index of each indicator is the percentage of the sustainable score relative to maximum score. It indicated the significance of each indicator in sustainability agriculture. It is used to compare indicators within household and the commune.

In additional, Duc (2005) also used SIA to assess the sustainability of crop production systems at household and commune levels in mountainous area of Thua Thien Hue province, Vietnam. In the study, he found out that SIA was useful method in a simple study in which weighting of indicators did not considered, in other words, SIA was best when it applied to assess the sustainability in definite condition.

2.4.3 AMOEBA diagram

In this approach, the results obtained by monitoring the indicators are summarized and integrated. To achieve an adequate integration and synthesis of the results, the process of evaluation followed three major stages:

1. Selecting indicators of performance on different scales and related to different perspectives.
2. Defining feasibility domains for selected indicators. Having chosen the variables on different axes, one must define a range of 'feasible' values for each indicator. Within 'feasibility domain' 'target values' may be added to the graph that reflects the goals expressed by the representatives of different perspectives.
3. Assessing current situation on a multi-dimensional state space. In this step, the actual value of each indicator is recorded on the graph. This makes it possible to visualize the position of the actual values.