CHAPTER 2

LITERATURE REVIEW

2.1 Concept of sustainable agriculture

The ever-increasing population of particularly undernourished and malnourished despite the population planning, production planning and economic policies has always been a concern in terms of feeding the world. This is further exacerbated by shrinking natural resources, which is constantly under pressure to produce more to equilibrate the global food requirement. The depletion of both renewable and non-renewable natural resources is the greatest threat to agricultural production systems. As appropriately stated by Powers and McSorley (2000), "conservation or sustainable management of the existing resources is of paramount importance if agriculture production is to be sustained far into the future". In a book "Doubly Green Revolution" (Conway, 1997) emphasizes that the present and future agricultural production should focus both on the increased production while managing the natural resources and environment. The fact is, sustainability is not a new concept but rather a prominent concept at the present time.

While there are no consensus on precise and operational meaning of sustainability, its meaning differ across space and time between individual. There seem to be more than 386 definitions only implies its relevance and importance to people (Rigby *et al.*, 2001).

To get a better perspective of the sustainability assessment principles, understanding the definition of sustainability "sustainable agriculture" is vital. Sustainable agriculture is a term that has been used to denote a more environmentally sound and socially responsible system of agricultural production than the traditional system in most western societies. Although there are literally hundreds of definitions of sustainable agriculture, one of the more widely accepted definitions, developed by the United State Department of Agriculture (Gold, 1999), is 'an integrated system of plant and animal production practices having a site-specific application that will, over the long-term:

- Satisfy human food and fiber needs
- Enhance environmental quality and the natural resource
- Make the most efficient use of nonrenewable resources and integrate
- Sustain the economic viability of farm operations
- Enhance the quality of life for farmers and society as a whole

It is important to note that this definition encompasses the three dimensions most closely associated with sustainable agriculture – the economic dimension, the environmental dimension and the social and community dimension. Truly sustainable agriculture is one that is economically profitable for farmers, preserves and enhances environmental quality, contributes to the well-being of farm households and nurtures local community development. Sustainable agriculture denotes a holistic, systems-oriented approach to farming that focuses on the interrelationships of social, economic and environmental processes.

In view of the above elements, sustainability may be regarded as one of the most challenging and, at the same time most fuzzy contemporary paradigm (Bosshard, 2000). However, it can be concluded that sustainability is a multi-dimensional concept. The importance of the sustainability of agricultural systems and the need to develop appropriate ways to measure sustainability has been long recognized. 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 over time depends on the practices at the present time and in future.

2.2 Indicators of sustainable agriculture

Sustainability indicators are seen as necessary to put into effect the concept of sustainability into use and management of resource and assessing their impact. Many researchers have investigated to develop appropriate sustainability measures to facilitate decision-making processes. Decision to know exactly the level of production and profit that must be sustained and what level of each of the various resources should be maintained, at what level of human population can it be sustained and for how long it can be maintained are necessary. Obviously these questions require long-term anticipation and planning to successfully continue sustainability over the long term (Powers and McSorley, 2000).

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 ecosystems, appropriate technology, maintenance of the environment, cultural diversity, and satisfaction of the basic needs.

For any study on sustainable agriculture, the question arises as to how agricultural sustainability can be assessed. Although precise measurement of sustainable agriculture is not possible, ‘‘when specific parameters or criteria are selected, it is possible to say whether certain trends are steady, going up or going down’’ (Pretty, 1995).

According to Lynam and Herdt (1989), sustainability can be assessed through examining the changes in yields and total factor productivity. The workshop organized by the Institute for Low External Input Agriculture (ILEIA, 1991) mainly emphasized productivity, security, continuity, adaptability and integrity as indicators of sustainability. Beus and Dunlop (1994) considered agricultural practices such as the use of pesticides and chemical fertilizers, and maintenance of diversity as measures of sustainability. For sustainable agriculture, a major requirement is the sustainable management of land and water resources. An International Working Group (Smyth and Dumanski, 1993) has concluded that the maintenance or enhancement of productivity, reduced risk, natural resources conservation, promotion of economic viability and social acceptability are essential conditions for sustainable land management. Gowda and Jayaramaiah (1998) used nine indicators, namely integrated nutrient management, land productivity, integrated water management, integrated pest management, input self-sufficiency, crop yield security, input productivity, information self-reliance and family food sufficiency, to evaluate the sustainability of rice production in India.

The sustainable indicators are also typical and different between different levels. The series of index as indicators for sustainability assessment at farm level are used by Rigby *et al.* (2001). They also reported that in Malaysia five indicators (i) insect control (ii) disease control (iii) weed control, (iv) soil fertility maintenance and (v) soil erosion control were used to assess the sustainability of agriculture at farm level. In contrast Gomez et al., 1996 used (i) yield (ii) profit, (iii) frequency of crop failure, (iv) soil depth, (v) organic C and (vi) permanent ground cover as indicators at farm level. But in watershed level, to assess sustainability at watershed level in Mae Chaem Catchment in Northern Thailand Praneetvatakul *et al.* (2001) developed specific indicators for agricultural sustainability are developed at different levels: household, village, and subcatchment, namely soil erosion, water shortage, health impact from chemical pesticide use, productivity, labor, food sufficiency, etc.

Although many indicators have been developed, they do not cover all aspects of sustainability. Moreover, due to variation in biophysical and socio-economic conditions, indicators used in one country are not necessarily applicable to other countries.

2.3 Assessing sustainability

The sustainability assessment methodology widely varies within and between the levels at which assessment is done. Generally, agricultural systems are evaluated at three levels (farm, watershed/catchments and regional level). Sustainability indicators are established based on information from various sources or means (secondary data, participatory approaches or laboratory analysis). Rigby *et al.* (2001)

used method of scoring of the indicators based on the perception of the farming. Simple scores (0-5) and (negative impact and positive impact) were used. Similarly, in an attempt to develop indicators for sustainable land management based farmer survey in Vietnam, Indonesia and Thailand, Lefroy *et al.* (2000) used secondary data source, interview and participatory rural appraisal and farmer participatory techniques with selected groups of farmers from three countries. Other situation, to develop understanding of the sustainability measure, Tellarini and Caporali (2000) used input/output methodology for farming system analysis in terms of both energy and monetary values, measurements that are sufficiently homogenizing and comprehensive to document patterns of agroecosystem transfer of biophysical entities and socio-cultural values. Those are illustrations for assessing sustainability at the farm level, how about the assessment of sustainability at watershed/catchment level. Kammerbauer *et al.* (2001) in their study in a typical watershed in central Honduras, special attention was given to indigenous and qualitative indicators for development. Qualitative and quantitative indicators of the state of production factors and the environment can define the resource conditions. Participatory approach was used to draw sustainable watershed vision considering the basic human needs and the maintenance of life support systems for current and future generations. Identification of indigenous indicators was achieved through intensive discussions on relevant issues related to community development. Both the participatory and laboratory analysis was used to draw multi-faceted development tendencies in the watershed and community, and to identify the implication of natural resource policy design for mountainous regions. Spatial and temporal databases were used to assess the changes in land cover and landscape use patterns over time.

Thus, sustainability cannot be measured per se, but rather can be seen through the comparison of two or more systems. Quantitative, qualitative, and graphical each technique has its relative advantages and disadvantages. When properly designed, qualitative techniques may provide more effective methods for identifying problems than complex numerical analysis (Masera and Astier, 2002).

Munasinghe (1993) suggested that when sustainability for development was an ultimate goal, this required the balancing of environmental, social, and economic systems. The decision-making techniques, in such a context, should be redirected towards formulation of alternatives that meet various sustainability criteria and help to arrive at the best compromising solution for making a transition towards sustainable use of natural resources. In such a situation, multi-criteria decision-making (MCDM) techniques are particularly helpful. The use of two widely popular MCDM techniques is compromising programming (CP) and analytic hierarchy process (AHP) (Tiwari *et al.*, 1999).

Various MCDM techniques have been developed and applied in the past for regional planning, agricultural land and water management purposes. Recently, the use of MCDM techniques has been emphasized for application in environmental-economic decision making where all the objectives, or criteria cannot be quantified in monetary units (Munasinghe, 1992). The choice of a particular method for environmental-economic decision-making, however, is guided by a trade-off between comprehensiveness and objectivity (Janssen, 1991). Various studies in the past have used MCDM techniques in making environmental-economic decisions. For example, Hafkamp and Nijkamp (1986) used MCDM techniques for integrated economic-environment-energy policy analysis. The multi-regional model was developed constructing mutually interactive three parallel layers-economic, employments and environment using CP techniques. Zekri and Romero (1993) used the MCDM approach to find a best compromising solution combining various public and private concerns, such as net present value (NVP), employment, water consumption and energy use, in agriculture. Likewise, Laxminarayanan *et al.* (1995) used a multi-objective modeling approach for making decisions involving trade-off between soil erosion and water quality.

Approaches commonly known by researchers in monitoring sustainability include environmental or extended cost–benefit analysis, MCDM, and sustainability indicator analysis (SIA) (Mueller, 1997). Among them, the SIA is considered as the least formal approach. It simply aggregates and integrates diverse information into a meaningful form. With less data and analytical skills required, this indicator becomes a significant and flexible analytical tool for sustainability assessment.

According to Pastore and Giampietro, agriculture operates on the interface of two complex, hierarchically organised systems: the socio-economic system and the ecosystem. So in any defined farming system one will always find legitimate and contrasting perspectives with regard to the effects of changes in the system, and the effects are not likely to result in absolute improvement for all stakeholders. Hence, a 'correct' assessment of agricultural performance should best be based on an analysis of trade-off that reflect the various perspectives, both positive and negative, with regard to the effects that a proposed technological or policy change will induce on the various scales and actors involved. A methodological tool, the AMOEBA multi-dimensional reading that can be used to characterise farming system performance in an integrated way on various scales and according to various perspectives.

Although these various efforts made in the past have attempted to incorporate both the economic and environmental dimensions, it is equally important that people's perceptions are also considered while making decisions. While developing a framework for environmental-economic-social decision-making, these various criteria and concerns have to be taken into consideration. In this paper, the use of three widely popular techniques is SIA, AHP, and the AMOEBA multi-dimensional reading.

2.3.1 Analytic hierarchy process (AHP)

In everyday life, decision making plays most important role as there are numerous alternatives to tackle the situation be it personal, general or global. It is plays an important role when there are multiple objectives. Although, it is done through intutions, most of the times a scientfically valid approach is prefered to make correct decision with the hope that decision taken brings forth the desired outcome and not vice-versa. While there are numerous methods, analytic hierarchy process (AHP), which builds on soft system methodology is becoming a widely used approach in diverse situations ranging from simple selection of species (Stokes, 2002) to complicated situation such as fisheries management (Leung *et al.*, 1998), designing buffer zone (Li *et al.*, 1999), forest certification (Kurttila *et al.*, 2000), environmental impact assessment (Ramanathan, 2001).

In real situations, there are many, often conflicting objectives and models are needed to handle such multiple objectives. There are a number of fundamental problems when there are multiple objectives. What-so-ever, the goal of any decision making process is to choose the “fair” alternative that aggregates the preferences of the decision makers. It should balance those objectives in a fair way. One technique that is used is the AHP, which uses very simple calculations to try to put numerical values on factors and alternatives.

AHP developed by Saaty (1980), is a flexible, yet structured, methodology which enables an individual (or a group of individuals) to define a specific problem and derive a solution based on the individual’s (or the group’s) own experience of the problem. AHP is a decision-making method based upon division of problem spaces into hierarchies, as visualized through the use of tree maps, which pack large amounts of hierarchical information into small screen spaces. Two direct manipulation tools, presented metaphorically as a "pump" and a "hook," were developed and applied to the tree map to support AHP sensitivity analysis. Apart from its traditional use for problem/ information space visualization, the tree map also serves as a potent visual tool for "what if" type analysis.

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. These elements may be divided into sub-elements and so on, thus forming a hierarchical decision tree. Once the hierarchical problem definition has been established, these criteria are weighted individually at every level relative to each other; prioritization of the alternate solutions can then be obtained via evaluation of these weights.

In a very simplistic explanation, AHP establishes hierarchy of decision using weights for each criterion and alternatives. It finally gives the ranking of each alternative through a very simple calculation. It can be classified into four major steps as given below:

Step 1: Structuring of the decision problem into a hierarchical model
Step 2: Making pair wise comparisons and obtaining the judgmental matrix
Step 3: Local priorities and consistency of comparison
Step 4: Aggregation of local priorities (to obtain final priorities of the alternatives)

2.3.2 Sustainability indicator analysis (SIA)

Praneetvatakul *et al*. (2001) in the case study of Mae Chaem Catchment in North Thailand assessed the sustainability of agriculture at various levels including household, village, and sub-catchments. 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 of the environment, (v) cultural diversity, and (vi) satisfaction of the basic needs (Mueller, 1997). Sustainability indicators were established based on the criteria and scoring technique was used for assessment. All the indicators have been assumed to have equal importance in terms of their contribution to agricultural sustainability. Score identified for each indicator were ranked into three classes as non-sustained (N), conditional sustained (C) and sustained (S). The scores were aggregated and used to classify the households into different sustainability classes.

To assess the sustainability at the village level, the household aggregated scores are grouped at village level. For the village level comparison, coefficient index (N=0.2, C=0.4 and S=0.8) are multiplied with number of samples in respective class to calculate sustainability index, performance and performance percentage.

The sustainability index of each indicator is the percentage of the sustainable score relative to maximum score. It indicates the significance of each indicator in sustainable agriculture. It is used to compare indicators within household and the commune. The performance percentage indicates the overall performance of sustainability from all indicators. It is used to compare the relative sustainability levels of the communes.

2.3.3 The AMOEBA multi-dimensional reading

The basic idea of the AMOEBA reading is to provide a graphic representation of system performance as assessed over a certain number of aspects or qualities that cannot be expressed as a function of the others. In this way, it is possible to have an overall assessment by a visual recognition of the existing difference between the profile of expected (or acceptable) values and the profile of actual values over families of indicators of performance referring to non-comparable qualities.

In the field of natural resources management, the AMOEBA approach have proposed by Brink *et al.* (1991) as a tool for dealing with the multi-dimensionality of environmental stress assessment by using different indicators of ecological stress referring to events occurring on different space-time scales. The graphic representation of the system is simply based on a division of the plane of a 'radar diagram' into different parts, each describing a distinct view on the system. Within AMOEBA diagram, a number of axes referring to different indicators of performance are then drawn. This diagram shows, in qualitative terms, to what extent the objective has been met for each indicator, and it enables a simple, yet comprehensive, graphical comparison of advantages and limitations of management systems being evaluated.

The review presents a very fuzzy scenario, where high diversity in sustainability assessment methodology of agricultural systems exists. Despite the variations in methodology and indicators, it most importantly gives an impression of the challenges to assess and ensure sustainability of the agricultural systems. The review gives us an opportunity to understand the state of development in assessment of sustainability of agricultural systems. The use of various models and indicators also allows us to understand the relevance of the sustainability issue that is a burning issue in the present world.