Decision Support System for Evaluating Sustainable Land Management in Sloping Lands of Asia

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1. Abstract

Sustainable land management (SLM) in agriculture is a very complex and challenging concept. It encompasses biophysical, socioeconomic and environmental concerns that must be viewed in integrated manner. An international Framework for Evaluating Sustainable Land Management (FESLM) was recently developed to provide a base for addressing these issues comprehensively. SLM combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously satisfy the five pillars of SLM: maintain or enhance production services (productivity), reduce the level of production risk (security), protect the potential of natural resources and prevent degradation of soil and water quality (protection), be economically viable (viability) and be socially acceptable (acceptability). This paper deals with two issues related to SLM: (i) development of SLM indicators under the FESLM framework by conducting three case studies in Indonesia, Thailand, and Vietnam; and (ii) the use of the SLM indicators in developing an expert system based decision support system (DSS) which provides an opportunity to test and operationalize the FESLM concept for practical use.

The information and data collected from three case studies have been analyzed, according to the FESLM methodology, to develop SLM indicators that address the five pillars of the FESLM. After assessing the cause and effect relationships, with the associated impact for each indicator in an appropriate FESLM pillar, a knowledge base and a rule-base for SLM indicators specific to sloping lands in Asia was developed. Further, in developing the SLM indicators, we have integrated the knowledge from diverse sources such as: data from long-term IBSRAM network experiments in Indonesia, Thailand, and Vietnam; data from on-farm research trials; information about informal technical innovations from progressive farmers, extension workers; and knowledge from subject matter specialists such as agronomists and soil scientists. The DSS-SLM is targeted at extension workers and NGO staff, who can use the DSS-SLM to identify constraints to sustainable land management at the farm level by analyzing their farm management practices, and to suggest prescriptive measures to achieve sustainability. We plan

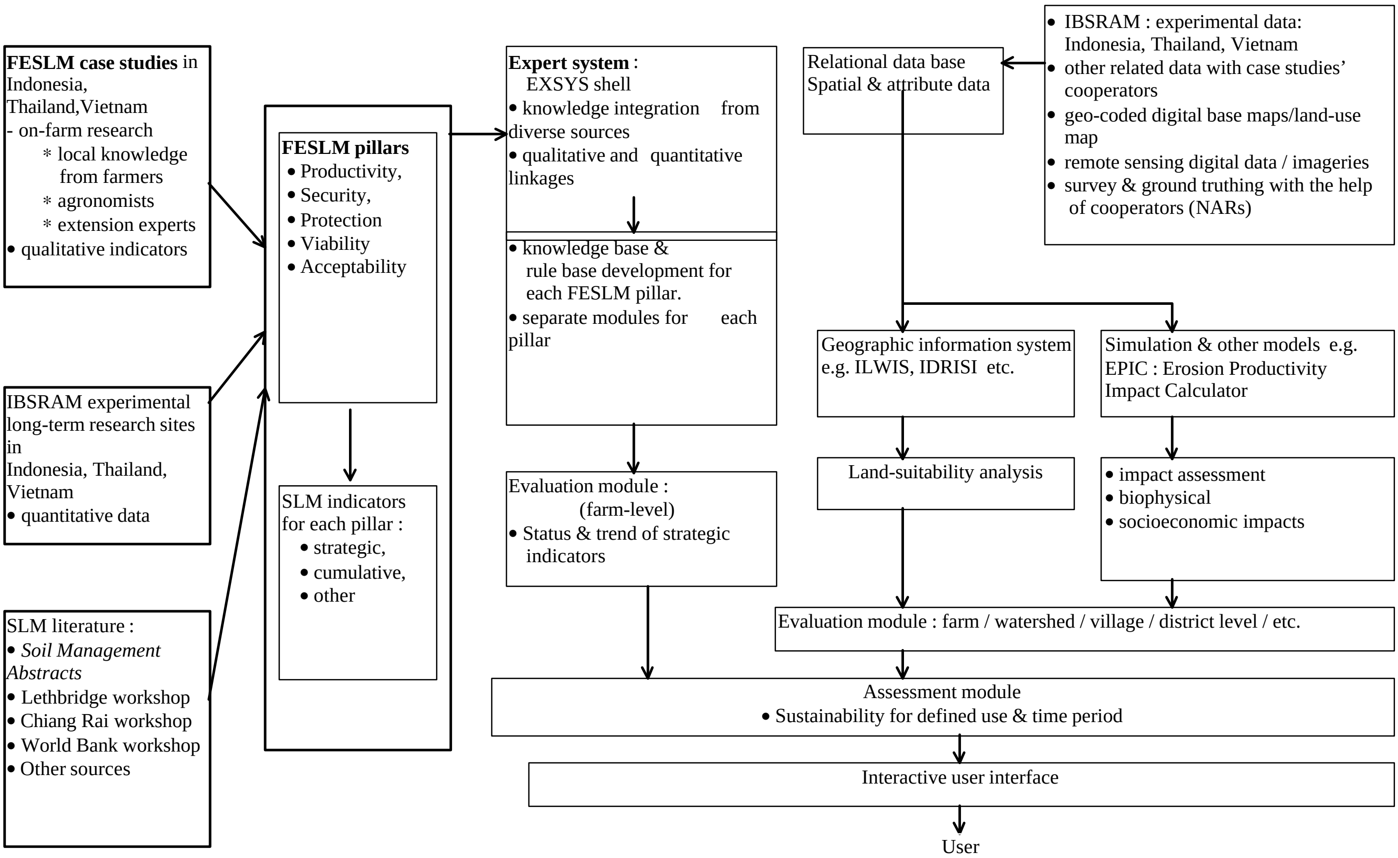
to upgrade the DSS-SLM by integrating geographic information system (GIS) and modeling components.
Agenda 21 provides a master plan for sustainable development at the global level. It highlights the need to address urgently the food security of an expanding population while addressing the associated environmental and resource management problems. Chapter 40 of Agenda 21 “information for decision making” highlights the importance of using appropriate information and information technology in the decision-making process. The need for information arises at all levels, from that of senior decision-makers at national and international levels to those of individuals and communities at the grassroots level. In this connection bridging the data gap and improving information availability are major areas of concern.

Sustainable land management (SLM) combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously: maintain or enhance production services (productivity), reduce the level of production risk services (security), protect the potential of natural resources and prevent degradation of soil and water quality (protection), be economically viable (viability) and be socially acceptable (acceptability) (FAO: 1993). Sustainable land management is complex and hard to assess in practice, requiring the understanding and integration of information from diverse sources. One promising approach to this problem is to develop indicators based on the five pillars of the international Framework for Evaluating Sustainable Land Management (FESLM). In the FESLM framework the development of SLM indicators from diverse knowledge sources and the use of these indicators for decision-making is a major challenge for decision-makers concerned about sloping land management. Under complex and unstructured problem scenarios, the use of decision support systems (DSS) at various levels of decision-making can be very helpful in promoting SLM. A DSS-SLM will help to identify or pinpoint the constraints or practices that hamper the achievement of sustainable land management.

We are particularly concerned with the needs of sloping land farmers in Asia, where poverty and soil erosion are serious problems. This paper reports progress in developing a DSS-SLM for sloping lands in Asia. We have developed a knowledge base (KB) for DSS-SLM in the form of SLM indicators based on the FESLM framework. and developed with national scientists from case studies in Indonesia, Thailand and Vietnam. The target users of our DSS-SLM are extension workers and NGOs in sloping lands of Asia. Extension workers and NGOs involved in technology transfer can use DSS-SLM to identify constraints in sustainable land management at farm level by analyzing their farm management practices. Based on the diagnosis using the DSS, they will be able to prescribe measures to achieve sustainability.

2. Decision support system for sustainable land management

A sophisticated DSS is an integration of many subsystems, including data bases, geographic information system (GIS) , analytical tools, expert systems, simulations, and a user interface. To ensure proper integration, all software subsystems must follow a unified framework and standard. To make any system extendible and easily modifiable, the code should be modular and consistently commented, indented, and structured (Jacucci et. al 1996). A schematic of the IBSRAM DSS-SLM under development is given in figure 1. Sustainable land management is a very complex problem where the process of SLM cannot be predicted and modeled with certainty. However, as we proceed and progress interactively, we develop a better understanding of the problem and can determine the future course of actions and decisions. In



such complex systems modeling the problem domain is a crucial step in the whole decision-making process.

Figure 1. Schematic representation of the IBSRAM DSS-SLM (under development)

The DSS-SLM provides an opportunity to test and operationalize practical use of an international Framework for Evaluating Sustainable
Land Management (FESLM) which can be realized with the application of state-of-the-art information technology tools. The universality of FESLM allows for development of a generic decision support system (DSS) which can be customized for local application by using indicators and criteria of local importance. In this project IBSRAM, in collaboration with Agriculture Canada and case studies' cooperators from Indonesia, Thailand, and Vietnam is developing a decision support system (DSS) to assist users in diagnosing sustainable land management problems and identifying constraints in achieving sustainability. The domain of the DSS is specific to hillsides and uplands in Southeast Asia. The DSS-SLM is targeted at the farm level for use by extension personnel, agribusiness, NGOs and others providing advice to producers. Its objective is to provide farmers with a selection of farm management and cropping practices that are sustainable within their region and environment. It will also assist extension personnel to design packages of technologies for sustainable land-use systems, in addition to serving as a tool for technology transfer and training for new extension agents and innovative farmers.

3. Methodology for development

We have undertaken to develop SLM indicators that integrate knowledge from diverse sources such as IBSRAM long-term experimental research data, FESLM on-farm research case studies, and informal technical innovation from progressive farmers, extension workers and experts such as agronomists and soil scientists. Three case studies under the FESLM framework are being conducted in Indonesia, Thailand, and Vietnam. A comprehensive set of guidelines for FESLM case studies, including the use of participatory rural appraisal (PRA) methods, was to ensure scientific rigor and a standardized approach in field data collection. The information and data collected have been analyzed, according to FESLM methodology, to develop indicators along the five pillars of FESLM i.e. *productivity, security, protection, viability* and *acceptability.* To enhance the nature and role of the indicators, each has been categorized as *strategic*, or *cumulative* or *suggestive*. After establishing the cause and effect relationship, with the associated impact for each indicator in each FESLM pillar, a knowledge base and a rule-base for SLM indicators was developed. In order to understand the requirement of DSS-SLM users, the domain of DSS-SLM users (i.e. the extension worker) has been studied through a series of interviews. A modular approach is being followed to develop a DSS-SLM. During the current phase of DSS-SLM, the major component of the DSS relies on expert system module. However, in subsequent phases other components such as a geographic information system (GIS) and models for impact assessment will be integrated.

4. Knowledge-base development for sustainable land management

The expert system technology is a major component of the DSS-SLM. One of the key outputs of research in the area of artificial intelligence has been a technique that allows the modeling of information at higher levels of abstraction. These techniques are embodied in languages or a tool that allows programs to be built closely resembling human logic in their implementation. Therefore, these techniques are easier to develop and maintain. These programs, which emulate human experience in well-defined problem domains, are called expert systems. Knowledge acquisition and knowledge-base development are crucial to the success of expert systems. Knowledge acquisition is the process of extracting, structuring and organizing knowledge from diverse sources. The knowledge base of the DSS-SLM is being developed in the form of sustainable land management (SLM) indicators. A flow diagram for the knowledge acquisition process is given in Figure 2.

The SLM indicators developed along the five pillars of FESLM i.e. *productivity, security, protection, viability* and *acceptability* are given in table 1 to 5*.* The SLM indicators table provide the threshold, their quantitative and qualitative ratings. Their score and ranks have been assigned according to the type of indicator (strategic, cumulative or suggestive). Based on the knowledge-base, the rule base for SLM indicators has been established. The trend of SLM indicators over time, in combination with their threshold values, helps the evaluation of the sustainability of land management practices of sloping land farmers in Asia. The knowledge-base and rule-base acts as the back bone of the DSS-SLM. The inference engine helps in processing the knowledge-base and rule-base of SLM indicators.

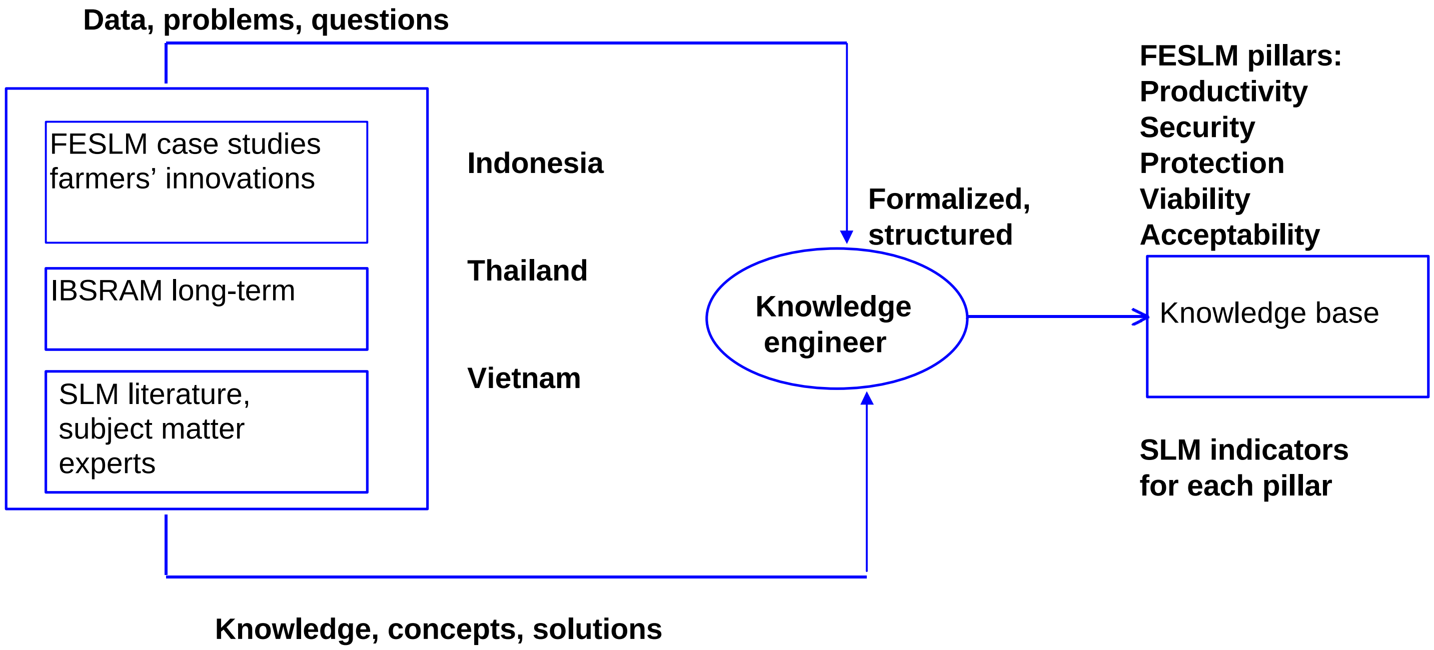


Figure 2. Knowledge acquisition process for SLM indicators.

5. Sustainability Evaluation

The SLM indicators along five FESLM pillars have been transformed into 26 user friendly questions. Each question provide multiple choice answers. Some examples of DSS-SLM questions are given below.

- Land holding size is
  - less than 1 ha
  - 1 to 2 ha
  - more than 2 ha
- The prominent annual cropping intensity has been
  - Two to three crops with conservation measures
  - Two to three crops without conservation measures
  - One crop with conservation measures
  - One crop without conservation measures

- The land tenure status for the farm has been
  - full ownership
  - long term user rights
  - no official land title

In SLM evaluation, the extension worker or local NGO worker (user of DSS-SLM) facilitates the provision of information by the farmer. The information facilitators are expected to have knowledge of local agroclimatic conditions and farming practices. The relevant information for the farm under evaluation is put into the DSS-SLM system. Based on the information for a specific farm, the DSS-SLM provides an assessment of the sustainability status of land management practices by the farmer. The sustainability status, for each FESLM pillars i.e. *productivity, security, protection, economic viability* and *social acceptability,* is provided as one of the four following possible scenarios.

- Land management practices *meet sustainability* requirements
- Land management practices are marginally above the threshold for *sustainability*
- Land management practices are marginally below the threshold for *sustainability*
- Land management practices *do not meet sustainability* requirements

Table 1. Productivity Indicators: Thresholds, Qualitative and Quantitative Ratings and Type, Scores , Rank, and Value

Indicators	Type *	Threshold	Qualitative Ranking	Quantitative Ranking	Score (a)	Rank (b)	Value (a x b)
Yield	1	> 25% or more Yd. reduction of the average of community	Yd Reduction:High	> 25 %	10	10	100
			Medium	10 - 25 %	10	5	50
			Low	< 10 %	10	7	70
Soil Colour: Organic C	1	< 1.2 %	High : Dark soil	> 1.2 % (Yd red. 0 %)	10	7	70
			Medium: Brown soil	1-1.2% (Yd. red. 0-20 %)	10	5	50
			Low: Yellowish	< 1 % (Yd red. > 20 %)	10	7	70
Plant growth and leaf colour: Soil nutrient N	2	< 0. 5 %	High: Dark green leaves healthy, vigorous growth	> 0. 5 %	7	7	49
			Medium: Colour normal, moderate growth	0.2 - 0.5 %	7	5	35
			Low: Yellowish leaves, stunted growth	< 0.2	7	7	49
P	2	> 15 ppm	High: Growth normal, colour normal	> 15 ppm	7	7	49
			Medium: Growth normal	8-15 ppm	7	5	35
			Low: Older leaves purple, stunted growth	< 8 ppm	7	7	49
K	2	> 90 ppm	High: Normal growth,	> 90 ppm	7	5	35
			Medium: normal plant growth	60 - 90 ppm	7	5	35
			Low: leaves yellowish from tip running along edge, and further expand, older leaves show symptoms first	< 60 ppm	7	10	70

***Indicators type and their score : strategic (1)=10; cumulative (2) =7 ; suggestive (3)=3; Relative ranking: 1 to 10. Value = score x rank**

Table 2. Security Indicators: Thresholds, Qualitative and Quantitative Ratings and Type, Scores ,Rank, and Value

Indicators	Type*	Threshold	Qualitative Ranking	Quantitative Ranking	Score (a)	Rank (b)	Value (a x b)
Average annual rainfall (amount and period) (ET by Penman and Montieth)	1	< 1200 mm, spread over 4 - 8 months	Low: Yd red. > 25% Normal: Yd red. 0% V. High Yd. red. >25%	< 1200 mm, < 4 months > 1200 - < 2400 mm during 4-8 month >2400 mm, > 8 months	10 10 10	10 7 10	100 70 100
Biomass: (% of crop residue) ploughed back to land	2	< 50 % of cop residue > 3 years continuously	High amount for long time High amount for short time Low amount for long time low amount for short time	> 50% for > 3 years > 50% for < 3 years < 50% for > 3 years < 50 % for < 3 years	7 7 7 7	7 5 5 5	49 35 35 35
Drought frequency	1	< 800 mm RF > 2 yrs consecutively	No Drought: Yd. red. 0-25 % Drought: Yd. red. > 50%	Rainfall > 800 mm Rainfall: < 800 mm for > 2 years	10 10	7 10	70 100

* **Indicators type and their score : strategic (1)=10; cumulative (2) =7 ; suggestive (3)=3; Relative ranking: 1 to 10. Value = score x rank**

Table 3. Protection Indicators: Thresholds, Qualitative and Quantitative Ratings and Type, Scores, Rank, and Value

Indicators	Type *	Threshold	Qualitative Ranking	Quantitative Ranking	Score (a)	Rank (b)	Value (a x b)
Erosion	1	4.5 cm or more during last 7 years	Low: Yd. red. 0-10%	< 0.7 cm	10	7	70
			Medium: Yd. red. 10-25%	0.7 - 4.5 cm	10	5	50
			High: Yd red. > 25%	> 4.5 cm	10	10	100
Cropping system & extent of protection	2	Double cropping	With Hedge row: High: Double cropping	Extent of protection: 80-100 %	7	10	70
			Medium: Mono cropping	50- 80 %	7	7	49
			Without Hedge row: Medium: Double cropping	50-80 %	7	7	49
			Low: Mono cropping	0 - 50 %	7	5	35

* Indicators type and their score : strategic (1)=10; cumulative (2) =7 ; suggestive (3)=3; Relative ranking: 1 to 10. Value = score x rank

Table 4. Economic Viability Indicators: Thresholds, Qualitative and Quantitative Ratings and Type, Scores, Rank, and Value

Indicators	Type*	Threshold	Qualitative Ranking	Quantitative Ranking	Score (a)	Rank (b)	Value (a x b)
Benefit cost ratio	1	B/C ratio 1.00 or more	High Medium Low	> 1 1 - 0.8 < 0.8	10 10 10	10 7 5	100 70 50
Percentage of off-farm income	2	25 % or more	High Medium Low/none	> 25 % 10-25 % < 10 %	7 7 7	7 5 7	49 35 47
Difference between farm gate price and nearest main market price	2	> 15 %	High Medium Low	> 50 % 15 - 50 % < 15 %	7 7 7	7 5 7	49 35 49
Availability of farm labour	2	1+1 man year	High Medium Low	> 2 man year 1-2 man year 1 man year	7 7 7	7 5 7	49 35 49
Size of farm holding	3	1 ha	High Medium Low	> 1 ha 0.5 - 1 ha < 0.5 ha	3 3 3	7 3 5	21 9 15
Availability of farm credit	3	50 % or more of the demand	High Medium Low	> 50 % 25 - 50 % < 25%	3 3 3	5 3 3	15 9 9
Percentage of farm produce sold in market	2	50 % or more	High Medium Low	> 50 % 25 - 50 % < 25	7 7 7	5 3 3	35 21 21

* Indicators type and their score : strategic (1)=10; cumulative (2) =7 ; suggestive (3)=3; Relative ranking: 1 to 10. Value = score x rank

Table 5. Social Acceptability Indicators: Thresholds, Qualitative and Quantitative Ratings and Type, Scores , Rank, and Value

Indicators	Type*	Threshold	Qualitative Ranking	Quantitative Ranking	Score (a)	Rank (b)	Value (a x b)
Land tenure	2	Full ownership of land	1. Full ownership 2. Log term user rights 2. No official land title		7 7 7	7 5 7	49 35 49
Support for extension services	3	One extension worker per 100 farms	1. Full extension support 2. Very low extension support 3. No extension support		3 3 3	7 5 7	21 15 21
Health and educational facilities in village	3	One school and one health center	1. There are adequate educational and health facilities in the village 2. There is shortage of educational and health facilities 3. The are no educational and health facilities		3 3 3	7 5 7	21 15 21
Percentage of subsidy for conservation packages	2	50 % subsidy	1. There is sufficient subsidy available 2. There is limited subsidy 3. There is no subsidy	1. 50 % or more 2. < 50 %	7 7 7	5 5 5	35 35 35
Training of farmers soil and water conservation	3	Training once in three years	1. There has been sufficient training 2. There has been no training	1 Once or more in three years 2. No Training	3 3	5 5	15 15
Availability of Agro- input within 5-10 km range	3	Easy access to agro-chemicals and seeds etc.	1. Agro-inputs are available as per requirements. 2. Inputs are available in limited manner 3. No inputs are available		3 3 3	5 5 5	15 15 15
Village road access to main road	3	Village road has full access to main road	1. Village road has full access to main road 2. Limited access to main road by motor 3. No access to main road by motor	1. 80-100 % road ready 2. 50-80 % road ready 3. < 50 road ready	3 3 3	7 5 5	21 15 15

* Indicators type and their score : strategic (1)=10; cumulative (2) =7 ; suggestive (3)=3; Relative ranking: 1 to 10. Value = score x rank

6. SLM constraints and prognosis

The identification of SLM constraints is one of the major objectives of the DSS-SLM. The sustainability status evaluation will help in identifying specific indicators that constrain the achievement of sustainable land management. The subsequent development of DSS-SLM will concentrate on prognosis aspects of SLM. The prognosis module will help provide potential solutions to farmers to overcome constraints in SLM. The knowledge base of the prognosis module will be based on farmers' indigenous innovations and improved practices recommended by experts. Further, in order to improve the analytical ability and visualization aspects, spatial analysis and modeling dimensions will also be integrated in future development of the DSS-SLM.

7. References

Smyth, A.J. and Dumanski, J. 1993. FESLM: An international framework for evaluating sustainable land management. A discussion paper. FAO. Rome, Italy. World Soil Resources Rep. 73. 74pp

Jacucci, G. , Foy, M. and Uhirk, C. 1996. Developing transportable agricultural decision support system: Part 1. A conceptual framework. Computers and Electronics in Agriculture 14: 291-300

Jacucci, G. , Foy, M. and Uhirk, C. 1996. Developing transportable agricultural decision support system: Part 2. An example. Computers and Electronics in Agriculture 14: 301-315