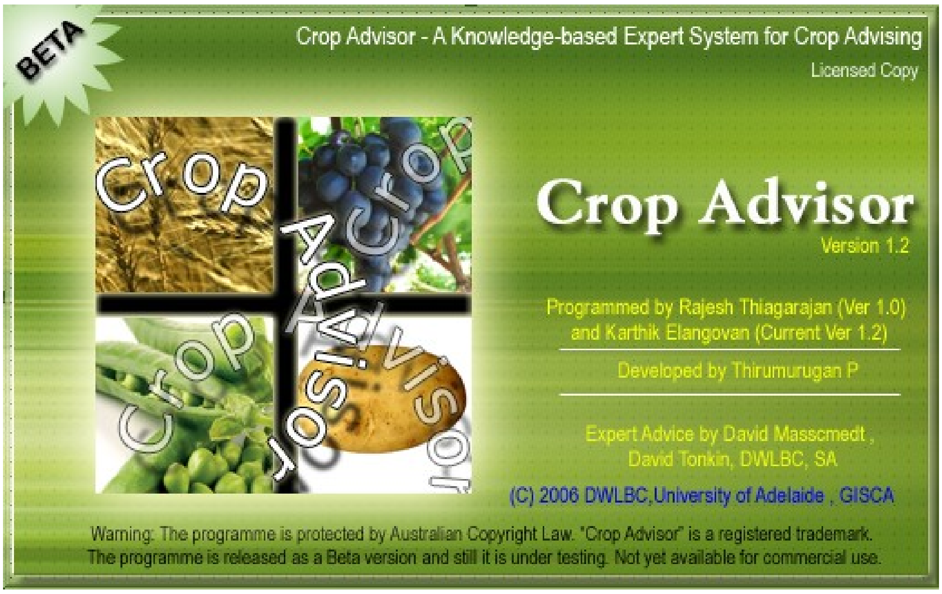
KNOWLEDGE-BASED EXPERT SYSTEM FOR AGRICULTURAL LAND USE PLANNING



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PREFACE

The knowledge-based expert system outlined in this thesis might seem redundant for a developed country like Australia. However, such a system is an essential requirement for developing countries. This expert system was conceived with the needs of Indian farmers in mind, who often do not have access to expert knowledge and advice in agriculture. The expert system is intended to give customized expert advice, anytime and anywhere. Due to the non-availability of geographic data from India, restricted time and financial resources, a study area in South Australia was chosen for conducting the research. The system uses knowledge-bases pertaining to South Australian agriculture, land use practices and crops. The expert system should ideally work for any geographic datasets with necessary changes applied to the knowledge-bases. The Department of Water, Land and Biodiversity Conservation (DWLBC), South Australia has supplied the essential data used for the development of this expert system, which is also beneficial to DWLBC, as the current thesis explores a knowledge-based approach and builds on the existing land evaluation computer program used by the DWLBC in evaluating land and suggesting suitable crops.

ABSTRACT

The research constitutes a ***knowledge-based*** *approach to* ***land evaluation for selecting suitable agricultural crops for a land unit****. This thesis presents the design, and development of a prototype Knowledge-based Spatial Decision Support System (KBSDSS) -"Crop Advisor"- for evaluating land resources and choosing suitable agricultural crops for a farm unit. The prototype "Crop Advisor" expert system (ES) utilises multiple knowledge rules to determine suitable, optimal crops for a farm unit considering the farm unit's resources. It considers the land evaluation process as a group-decision making process involving many experts from diverse scientific domains. The expert system is powered primarily by human knowledge collected from a land evaluator or a crop expert. The knowledge base consists of representative rules to reflect physical, economic, environmental and social factors that affect the choice of land use. The expert system makes use of Geographic Information System (GIS) tools to manage spatial information that are required for the evaluation process. These powerful tools (ES and GIS) help in choosing a crop, from a group of crop choices that gives more economic benefits without compromising environmental values. The expert system model is tested on the soil and physiographic data provided by Department of Water, Land and Biodiversity Conservation, South Australia (DWLBC) and Primary Industries and Resources, South Australia (PIRSA). This knowledge-based approach to land evaluation is built on the land evaluation framework designed by the United Nations Food and Agriculture Organisation (FAO). The DWLBC model of land evaluation suggests a strategic land use plan at regional level considering soil, climate and physiography which eliminates non-feasible land use or crop choices. The "Crop Advisor" expert system takes such regional data and suggests, in consultation with the farmer, a group of suitable crop choices that are best in terms of physical, economic, social and political factors associated with a farm unit.*

DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and that, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text of the thesis.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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Signed:

Date: 14th, December 2007

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The research presented here is supported by **International Postgraduate Research Scholarship (IPRS)** and **University of Adelaide (UAS)** scholarships. I would like to express my sincere thanks to the Australian Government and the University of Adelaide for supporting me in these two years. It has truly expanded my realm of knowledge and experience.

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DEFINITION OF TERMS

The following terms and definitions are adapted in the present research thesis.

Land use:

Land use refers to the use of land for raising agricultural crops, dairy and livestock. The current research deals with land use at farm level, a mapping scale of 1:10,000.

Agricultural land evaluation:

The procedure for surveying and assessing land resources in a farm unit to find its suitability to grow agricultural crops is known as agricultural land evaluation.

Crop suitability assessment:

Crop suitability assessment is performed based on the results of agricultural land evaluation. It aims to select an optimal crop that is suitable for growing in a farm unit, based on physical, economic and socio-political factors associated with the farm unit.

Farm unit:

A farm unit refers to a parcel of land used by a farmer or land owner for agricultural purposes. It is defined by a field boundary and usually considered as a management unit for cultivation.

Agricultural land use planning:

Agricultural land use planning refers to the combined procedure of land evaluation for agriculture and crop suitability assessment. In this research, the term “agricultural land use planning” refers to the farm level assessment of land resources and factors that affect the use of land and the act of choosing the most feasible crop option for a farm unit.

Strategic land use planning:

The process of land evaluation and land use allocation performed by the government authorities at regional scale is termed as strategic land use planning. The scale of mapping is usually between 1:50,000 to 1:1,000,000.

Geographic Information System:

A set of tools for managing geographically referenced data and information for planning and decision-making purposes.

Heuristic Knowledge

Heuristic (from the Greek word "heuriskein" meaning "to discover") knowledge pertains to the process of gaining knowledge through experience, trial by error methods rather than by following a formal step-by-step process (Roy 2001). For example, heuristic knowledge includes the knowledge gained from experience, rules of thumb and trial-by-error methods.

Expert

"An expert is a person who has a comprehensive and authoritative knowledge of or skill in a particular area" (Pearsall 1998:647). Experts have prolonged or intense experience, practice or education in a particular field that goes significantly beyond any general or shallow appreciation.

Knowledge Base

A collection of rules, assertions and facts about a problem domain represented in a machine-readable format is termed as a knowledge base.

Expert Systems

An expert system is a program which attempts to emulate the knowledge and reasoning capabilities of a human expert in order to solve a specific problem. Expert systems derive knowledge from various sources in the form of rules and assertions.

Knowledge Acquisition

The process of acquiring knowledge from various sources and converting them into a machine-readable form is referred as knowledge acquisition. The knowledge may come from various sources such as human minds, books, research findings and other reliable sources.

Knowledge Engineer

Knowledge Engineer is the person responsible for acquiring knowledge and coding it into a knowledge base in machine-readable form.

User

User is the person who uses the expert system. It is assumed that a typical user is an owner of a farm who wants to choose an optimal crop for his/her farm unit.

CHAPTER 1
INTRODUCTION

1.1. Background to the research

Land evaluation is the procedure of assessing the capability of land for specific land use purposes (FAO 1976:1; 1983:5). The process of land evaluation forms a vital part of land management and helps in preparing a successful land use plan. The purpose of land use planning is to utilize available resources in a land unit to maximize economic returns without degrading environmental values. Multi-disciplinary knowledge is required for a comprehensive evaluation of a farm unit's resources and to identify its true potentials and limitations. In case of agricultural land use, the results of land evaluation can help in choosing the most suitable land use and a profitable crop for a farm unit. Land evaluators and crop experts help farmers to choose the most profitable crop that is best suited for a farm unit by assessing the farm unit's performance by observing its land characteristics. However, not all farmers have access to such agricultural advice and information, especially farmers living in the developing countries (Reddy & Ankaiah 2005:1906; Zijp 1994:3). By having an agricultural expert system, the problem of scarcity of experts, especially in Agriculture, can be overcome (Rafea 1998:35-3). The aim of this research is to borrow the human intelligence used by a land evaluator (crop expert) and use it to develop a knowledge-based expert system that can guide farmers to choose a suitable crop for their land unit.

This thesis develops a knowledge-based, agricultural land use decision support model for a farm-based crop suitability assessment. In particular, the research aims at designing and building a prototype expert system that will assist farmers in choosing a suitable agricultural crop that can be grown on a farm unit by analysing the physical, social and economic factors associated with that farm unit. In this process, it aims to use various dynamic knowledge-rules which contain scientific and heuristic[1] information. This introductory chapter discusses the purpose and significance of this research, outlines its scope, limitations and contributions and presents the organisation of the thesis chapters.

[1]Heuristic refers to the type of information or knowledge gained through experience not from scientific studies.

1.2. Purposes and significance of the study

The objectives of this research are twofold:

a. To develop a framework for designing a model for agricultural land evaluation and crop suitability assessment that uses knowledge from various sources and helps in selecting an optimal crop for a farm unit after a detailed evaluation of various contributing factors. The knowledge may be of scientific and or heuristic nature.
b. To develop a prototype expert system that utilises knowledge drawn from a human expert (crop advisor) to help farmers in choosing an optimal agricultural land use (and an optimal crop) for a farm unit by assessing a farm unit's physical resources and social, economic factors associated with it.

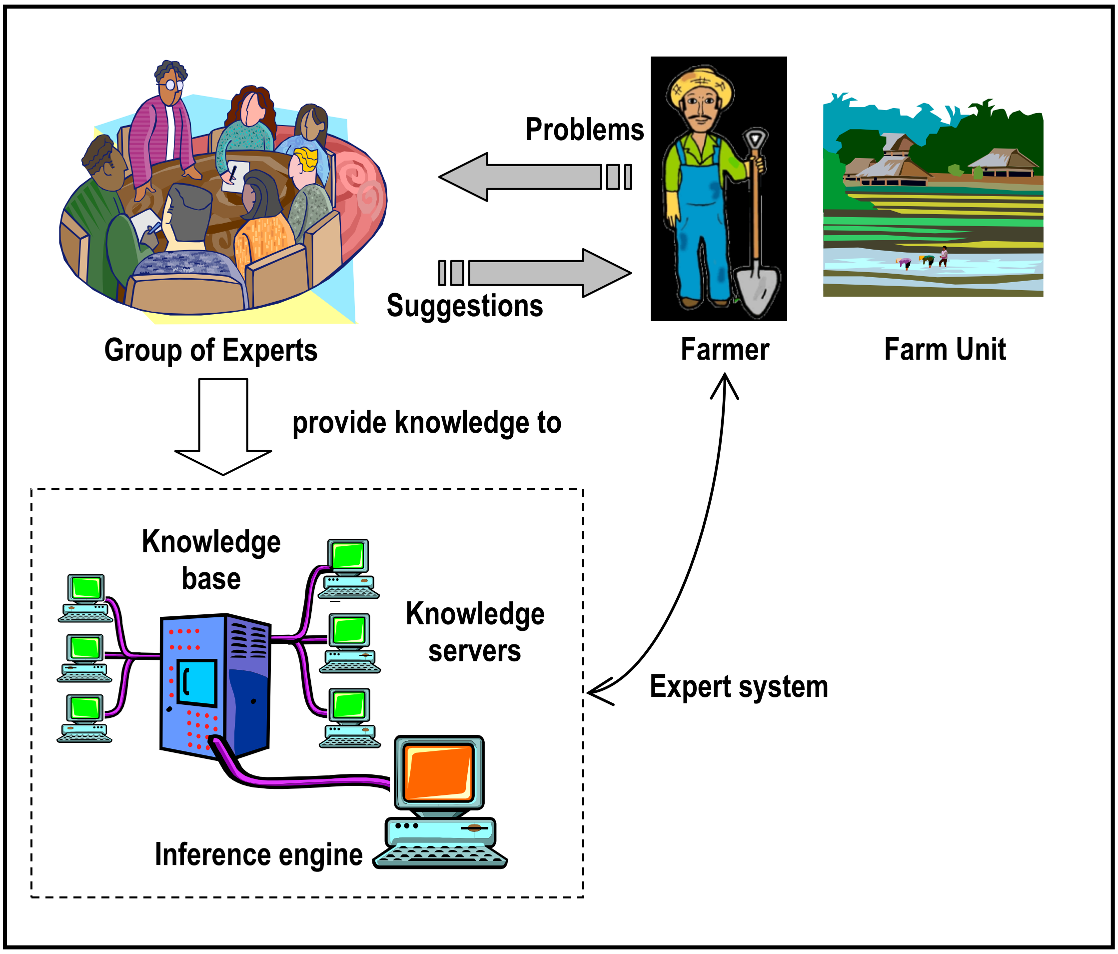
Land classification and land evaluation had been the domain of soil scientists until the early 1990's (Rossiter 1996:3). Mainly, because it was believed that soil was the key factor in deciding a particular land use. However, the land evaluation frameworks prepared by FAO (FAO 1983, 1985, 1994) have reiterated in their methods that it is not only the soil that influences the land use, but also a whole range of other factors, including climate, geology, water availability, social and economic objectives of farmers. As a result, the land classification and land evaluation approaches have undergone a radical change. Modern methods try to assess a land unit's suitability for different land use choices, unlike the traditional land evaluation methods (pre-1973) which classified a land on a general goodness factor (Diepen et al. 1991:153). The land evaluation procedure no longer belongs to or depends on, a single scientific domain. Indeed, an integrated and multi-disciplinary approach predominates (Beynon, Rasmequan & Russ 2002:127). Expertise from various scientific domains such as soil science, geology, groundwater, climatology, agriculture, environmental science, economics and politics are essential to choose an optimal crop or to develop a sustainable land use plan for a farm unit. Ideally, land evaluation should be carried out by a land evaluation expert working with a team of specialists who have expertise on various aspects of land use science (Rossiter 1996:3). The current research uses knowledge inputs from scientific studies and human experiences that come from various sources for land evaluation and crop suitability assessment.

Heuristic knowledge derived from human experiences, rules-of-thumb and trial-by-error findings have proved to be worthy in certain fields such as Agriculture and Medicine (Shu-

Hsien Liao 2005:94). In particular, land management scientists and land use planners have learnt much from their past experiences and also from the experiences of farmers. This knowledge plays a vital role in executing successful land resources management programs as reported by Wei, Jianbang & Tianhe (1992:322). Traditional Decision Support Systems (DSS) that use static algorithms find it difficult to solve such land use planning problems due to the inherent uncertainties involved in the decision-making process (McClean et al. 1995:79). The number of factors affecting a land use decision may increase or decrease depending on the scale and type of land use considered. Hence, decision support systems need to solve such land use planning problems with a human-type problem solving approach. Land use experts and crop consultants use a heuristic approach to arrive at an optimal land use plan (Detlefsen & Jensen 2004:58). Their approach combines scientific evaluation procedures, such as the results of soil testing, groundwater quality assessment, and heuristic assessment of social conditions, and political and market factors. Many decision support systems that deal with land development and land use planning problems require both spatial and heuristic analytical capabilities to solve problems (Somrang, Chuenpichai & Chuenpichai 2002:Section I). Expert Systems (ES) permit us to add the heuristic knowledge as facts and rules into DSS thereby providing heuristic analytical capabilities to the process of decision making.

Conventionally, the land owner approaches a group of experts to get a better land use plan. The experts analyze resource potentials and constraints to arrive at a feasible land use option for the land unit. In an ideal situation, various experts associated with land evaluation are invited to participate in the decision-making process to decide upon the best land use or a crop for a farm unit given certain feasible land use or crop choices. By negotiations and debates, an optimal consensus decision is determined. Various researchers (Geertman, Openshaw & Stillwell 1999:18; Ventura, Miller & Barry 2003:87; Leung 2003:201 and Randolph 2004:55) have stressed the need for decision support systems that could help people to use collective knowledge (from various sources) and help them in arriving at an optimal land use plan. This type of model, which supports collaborative decision-making, can be emulated by having an expert system. As shown in Figure 1.1, an expert system can use networked knowledge servers which provide required information and knowledge rules necessary for decision-making. The inference engine will then act as an intermediary between the user and knowledge bases to deliver suggestions to the user.

Figure 1.1 Traditional land use planning and a knowledge-based expert system



This research attempts to provide a solution by proposing a model for a knowledge-based land use planning approach that uses knowledge from human experts. The knowledge that is necessary for solving land evaluation and crop suitability analysis is collected from a crop expert and incorporated into the model. A prototype is developed to prove the concept of a knowledge-based approach by having a single knowledge base with knowledge rules collected from the human expert.

The study aims to achieve the development of a prototype expert system named "Crop Advisor", which can be used by land owners to choose an optimal crop for their farm units. To achieve this, the study uses a framework for multi-disciplinary, knowledge-based land use planning and decision-making, which will be detailed in Chapters 3 and 4. The framework is different from existing approaches as it involves two stages of progressive land evaluation for crop selection. In the first stage, a physical land evaluation at a mapping scale of 1:100,000 is made to eliminate crop categories that are not feasible for a region. This results in a group of suitable crop choices for a farm unit. Within the second stage, climate, economic, social and political factors, derived from user inputs, are used to suggest three crop choices that are best suited for the farm unit.

1.3. Research methodology

The research methodology consists of three phases:

1.3.1. Developing an appropriate model for agricultural land use decision making

This phase includes determining the factors required for agricultural land use planning and their relative importance towards the whole planning process. A comprehensive model is developed considering these factors and by consulting a crop expert who is specialized in land evaluation and land use planning. This phase forms the foundation on which the expert system will be developed, and is dealt within Chapters 5 and 6 of this thesis.

1.3.2. Developing the expert system

The model has to be translated into a schematic database which includes factors and their linkages that contribute towards possible agricultural land use decisions. This phase involves the collection of knowledge rules from a crop expert and coding them into a knowledge base. It involves development of a prototype to test the model with experimental data. Chapters 4, 6 and 7 aim to address this phase of the research.

1.3.3. Testing the expert system

When the expert system is ready, real world data will be introduced to it and tested for validity of land use decisions. The validity of the expert system will be judged by comparing its recommended crop choices with actual crops grown in the respective farm units. A series of iterative testing, feedback and improvement phases will build a satisfactory expert system. Chapter 8 deals with the testing methods and assesses the feedback from people who tested it.

1.4. Limitations of the current study

Though the scope of the project is substantially large, it has some inherent limitations that are briefly outlined below:

a. This research primarily focuses on amalgamating scientific and heuristic knowledge into the land use planning process and serves as a proof-of-concept for a knowledge-based decision-making approach. The quality of decisions depends on the quality of the knowledge base and the vastness of knowledge rules used in an expert system. Due to time constraints, the knowledge rules collected from the crop expert reflects only a few factors, which serve the purpose of validating a knowledge-based approach to agricultural land evaluation.
b. The research also discusses the importance of developing methods and tools for a collaborative, knowledge-based planning approach. References are drawn from the literature to support the advantages of multi-disciplinary, knowledge-based, collaborative approach over the other methods.
c. From a system development life-cycle point of view, the proposed methods and application provides only limited capabilities for use in real-world situation. As discussed earlier, the main focus of this research is to prove this concept works by developing prototype software and testing it with South Australian data. It is expected, however, that the early findings of this thesis may lead to future large-scale, commercial developments with substantive improvements. For example, with the involvement from many organisations and with more resources, the system can be developed into a real-time farm advice service for farmers through Internet. However, the use of the term 'real-time information' applies to weather and market factors which change frequently rather than soil and geological factors.

1.5. Theoretical contributions

The current research aims to make following theoretical contributions:

1.5.1. At the outset, in the Decision Support Systems discipline, this work elaborates a framework to design an expert system that could draw upon both scientific and heuristic expertise to arrive at land use decisions. Such an approach has been missing at the farm level, and this research is an attempt to fulfil the gap.

1.5.2. This research adds to the body of land use planning literature related to a multi-disciplinary, knowledge-based land evaluation and crop suitability decision-making at the farm level.

1.6. Practical contributions

The current research proposes to make the following practical contributions:

a. Develop a method to bring together scientific and heuristic knowledge to the agricultural land use planning process to suggest a crop best suited for any farm unit.
b. Establish a framework for adding knowledge into knowledge bases with procedures for easy modifications and updates.
c. Though the expert system may not find an immediate commercial application, it would be a pre-cursor for developing commercial knowledge-based, collaborative land evaluation and land use planning tools in the future.

1.7. Organisation of thesis chapters

The thesis has been organized into nine chapters. Following the Introductory, Chapter 2, Agricultural land use planning, elucidates the importance of land resources management and land use planning (LUP), the importance of geographic information systems (GIS) in LUP, and the process of land use decision-making for agriculture. It also discusses different frameworks that are practised for land evaluation and introduces the knowledge-based GIS approach and the current research framework. Chapter 3, Land suitability evaluation and crop selection, discusses the process of crop suitability assessment as practised by farmers and crop advisors and the factors involved in that process, their relevance and how it can be represented in a heuristic form. The fourth chapter, Computers in agricultural land use planning, traces the history of computing in agricultural land use planning, the disadvantages of their algorithmic approach, introduction of expert systems and the application of expert systems and GIS in agricultural land use planning. It also reviews the current decision support systems that use a knowledge-based approach to land evaluation. This chapter leads into Chapter 5, Land evaluation and crop suitability analysis, which presents an overview of the proposed expert system, the framework used for knowledge-based crop suitability assessment and explains the crop suitability model. It discusses the procedure for collecting knowledge from various sources, and validating and coding it into knowledge-bases. Chapter 6, Design and specifications, details the design standards and architecture of the expert system, software and tools used to create the expert system. Chapter 7 outlines the rationale and methodology adopted in developing the expert system, and the procedure of building the expert system. In Chapter 8, Testing and feedback, the process for testing the expert system, assessment of feedbacks and modifying the prototype is described. The last chapter, Chapter 9, Discussions and conclusions, presents the outcomes of the research, the theoretical and practical contributions made by the thesis and directions for further research.

1.8. Summary

This chapter has laid the foundations for this thesis by introducing the research objectives and significance of the research. It has also introduced the theoretical and practical contributions it expects to develop; and the limitations imposed on the research. Finally, it presented an overview of how the thesis chapters are organized.

CHAPTER 2
AGRICULTURAL LAND USE PLANNING

2.1 Introduction

This chapter analyses the importance of land and the necessity to manage land resources in a sustainable way. It reviews the concepts of land use, land evaluation and land use planning at various hierarchical levels and defines the relationship between land evaluation and land use planning. The chapter further elaborates the process of translating sustainable land use plans at the regional level to farm land use plans.

2.2 Land and its importance

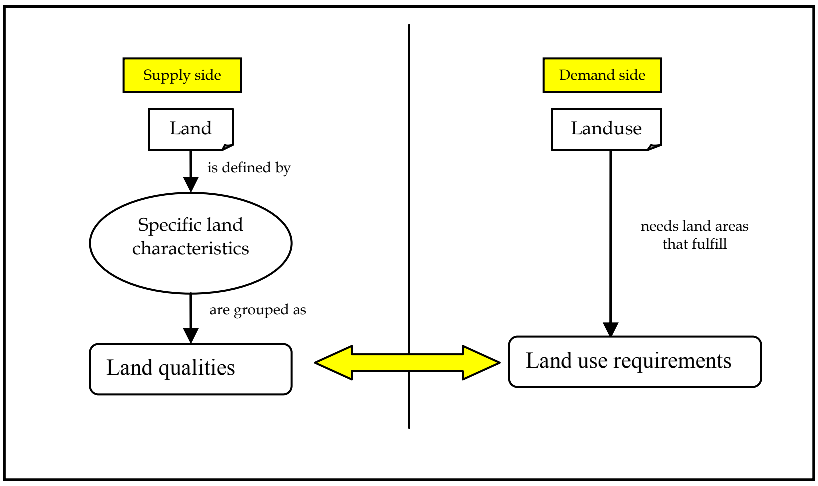
Land can be defined as a block of earth's surface which constitutes stable, dynamic or cyclic attributes of the biosphere that extend vertically above (atmosphere) and below (subsurface) an area (FAO, 1985:212). It is often characterized by the results of past and present human and animal (and impacts of climate) activities to the extent that these attributes exert a significant influence on future land uses (FAO 1980:6). Land is considered to be the basic building block of human civilization. Almost all living beings depend on land for their existence. In particular, humans heavily depend on land for food, clothing, fuel and shelter. Knowing its importance, ancient civilizations worshipped land as one of the five elements of nature, along with air, water, light (fire) and space (Dutt 2001:29; Wong 2004:16). In the pre-agricultural age, the community owned the land and it was free to use by anyone (Mather 1986:3). The community shared a responsibility for raising crops and preserved the lands with a sense of stewardship to pass on to the next generation. Slowly, the ownership of land moved to individual hands and hence the land use decision vested with individual interests. Land units were seen and managed as individual management units with profit maximization as the prime goal (Highsmith & Northam 1968:23) without much consideration about ecosystem. In other words, conservation of land and use of land in conjunction with surrounding ecosystem became the least priority among land owners. This was due to the lack of knowledge about ecosystem principles as farmers concentrated on short-term gains without worrying about the long-term impacts of their poor land use choices on the surrounding environment resulting in land degradation (Donovan & Case 1998:19). Such type of land degradation was more apparent in the developing nations as farmers practised cultivation in marginal lands with very little access to scientific methods. As a result, the environmental balance was disturbed and many of the land use choices practised by individual farmers were not sustainable over time. Intensive agricultural practices and unsustainable farming practices have deprived the soil of nutrients and paved the way for land degradation (Clay 2004:2). One remedy to this situation is to adopt sustainable land use practices.

In order to sustain the environmental balance, the land and its resources need to be managed in an effective way. To do this, an understanding of existing land resources and their current uses is essential. From historical times, land has been exposed to many risks such as degradation and over-utilization due to improper cultivation practices. Improper farming practices alone have reduced agricultural productivity and caused environmental damage in major parts of the world (World Bank 1997:1). Other factors, such as increasing population, decreasing yield and reduction of cultivable lands have created tremendous pressure on existing land resources. The marginal land areas available for agriculture are becoming exhausted all over the planet (Homer-Dixon 1999:63; Barrett, Place & Aboud 2002:1) and bringing additional lands into agriculture is no longer a feasible option. Agriculture land use faces intense competition from urban, industrial and recreational land uses. From the 1960’s, societies have faced a challenge to maximise agricultural outputs from existing land in a sustainable way. In his book “The Earth Can Feed Us” Osvald (1966) outlined ways of increasing food production. His proposals included bringing more lands into cultivation, increasing agricultural yield, using fertilisers and pesticides, plant breeding and mechanization of agriculture. Importantly, Osvald devotes a chapter (Osvald 1966:99-101) emphasising the importance of educating farmers of developing nations to increase overall farming efficiency. The knowledge for understanding land characteristics, their relations and effects on crop yield must be taught to farmers. Then, the farmers can undertake an accurate evaluation of existing land resources, utilising them to maximum advantage by employing better cultivation methods to increase crop yields. The prototype “Crop Advisor” expert system will attempt to fulfil this kind of knowledge transfer to developing countries.

2.3 Land evaluation and land use planning

A piece of land can be described in terms of its physical, chemical, environmental, economic and social attributes. These attributes are essential in determining the best use of the land. The process of determining, assessing and characterizing land attributes is known as land evaluation. The United Nations Food and Agriculture Organisation (FAO 1976:7) defines land evaluation as the process of assessing land attributes to find its potentials or constraints for specific (future) land use purposes. It is a multi-disciplinary science involving inventory, analysis and assessment of the physical, chemical, biological and socio-economic characteristics of land. Land evaluation is a key step in land use planning. Land use planning is the allocation of the best use for a land unit considering its resource potentials and limitations. It involves careful consideration of available resources and matching them with a proper land use activity that is also feasible from a socio-economic point of view (FAO 1993:1). Conventionally, land evaluation precedes land use planning. If land use planning can be considered as an economic activity, land qualities form the supply side and the land use requirements form the demand side – see Figure 2.1. It is essential to take stock of the supply side of land through land evaluation or assessment in order to cater to the demand side of land use, that is land use planning.

Figure 2.1 Land Evaluation as an economic activity, adapted from FAO framework (FAO, 1980:23; Leung 2003:167; Hubner & Moudon 2000:56)



The land use planning process should be motivated towards the land use choice which provides the greatest benefits from land without sacrificing environmental sustainability, as specified in Agenda 21 (United Nations 1992; Section II, Chapter 10). Agenda 21 advocated that the process of land use planning should follow an integrated approach where environmental, social and economic factors should be given equal importance. The process of land use planning requires the integration of multi-disciplinary knowledge including soil, groundwater, geological, environmental, demographic and economic sciences. It needs the involvement of experts from more than one scientific domain. In this process, human experts utilize their knowledge to analyse the resource potentials and limitations of a land unit to arrive at an agreeable land use plan. For this reason, land use planning is often regarded as a group activity that involves debates and negotiations between various experts, resulting in an optimal solution.

2.4 Strategic land use planning

Strategic land use planning aims to conserve and develop land resources for commonhood. The word ‘commonhood’ dictates that the activity of land use planning should satisfy the needs and aspirations of a broad range of people related to a piece of land. If land use planning is left within individual hands, it would in all probability, be used according to their own interest and may not be in conjunction with the interest of their neighbours. World Conservation Strategy (IUCN-UNEP-WWF 1980: Section 1) defines “conservation” as the act of managing the Earth’s resources for the optimal uses by current inhabitants and maintaining the ability to meet the desires and needs of future inhabitants. Also, it further defines “development” as the use of biosphere and the application of living and non-living resources for satisfying human needs and improving quality of life for everyone. Hence, it is essential to meet individual needs without compromising needs of the society for sustaining resources. A state or planning authority takes responsibility to make a land use plan for a region by considering the interests of commonhood in order to achieve fair use of resources by everyone. Trade-offs and conflict resolutions are part of land use planning and decision-making processes and require consensus among the associated stakeholders (Malczewski 1999:87), primarily the land owners and farmers of a region. In order to convince land owners, a regional land use plan should accommodate economic and social aspirations of land owners, risking abandonment of the plan by land owners if it does not. The regional land use plan should also consider short and long term implications of alternative land use plans and scenarios for a geographical region. This necessitates a comprehensive land use plan which should accommodate multiple land use options and crop choices for land owners of the region. Such a plan can be only achieved by a collaborative approach by involving stakeholders who will be affected by those decisions. At least, the necessities of different stakeholders can be translated into a set of decision criteria, and they can be included in the decision-making process.

2.5 Farm level land use planning

The purpose of a strategic land use plan prepared at a regional level is to guide land owners and farmers in a region to develop their own land use plans for their farm units. Regional strategic land use plans are developed after a preliminary assessment of soil and land resources and they provide a good indication of possible broad land use categories that the region can support. Government, through Land Resource Assessment agencies, usually carry out land surveys and employ classification techniques to determine suitable land uses for long-term sustainable production in an area and to identify preferred land use types (Shields, Smith & McDonald 1996:7). Such preferred land use types and crops suitability results for a region are published in the form of maps, often the mapping scale ranging from 1:1,000,000 to 1:50,000. These maps serve the purpose of guiding farmers and landowners to adapt and devise their own land use plans for their farm units. The government agencies also push these regional level land capability and suitability information to farmers and land owners to help them to produce “Whole Farm plans” or “Farm-level land use plans”.

Whole Farm Planning is an approach to teach farmers to adopt sustainable land use practices on their individual farm units by conveying information from regional soil surveys, land capability and land suitability classifications (Shields, Smith & McDonald 1996:10). In a typical “Whole Farm Planning” workshop session, farmers are assisted in mapping their own farm resources and classifying them into discrete map units to assess the land capability for each map unit (Garret 1993:11). The planning process considers the total farm assets, the soil, water, pastures, crops and livestock, and how to make the best use of them. Such resource inventorying and assessment measures are marked on the maps usually with the help of aerial photos of the farm. Such “whole farm maps” form as a guide to the utilisation optimal farm resources. A booklet published by Department of Conservation and Natural Resources, Victoria (Garret 1993) illustrates the method of producing whole farm plans and includes successful case studies by farmers.

Decision making at the farm level is often hampered by the scarcity of spatial data and reliable information at the large-scale. The data and data sources become sparse as the scale increases from 1:1,000,00 to 1:10,000. Farmers have to collect and interpret the required information, from sources such as aerial photos and satellite images. With the lack of knowledge and tools, this exercise is difficult, especially for farmers in developing countries.

Farm level decision making in agriculture is often risky because of uncertainties related to some of its input information, such as market and weather factors. The future decision-making models need to address unstructured, heuristic problems and the models must utilize more than one type of knowledge (Harsh 1998:7). With the scientific knowledge, the knowledge gained from experiences – heuristic knowledge – need to be used in decision making.

In the current research context, land use planning is relatively simple as it involves only individual farm units on a mapping scale of 1:10,000. The land use planning at farm level is carried out by the land owner, and is generally motivated by profit maximization utilizing available resources. Further, there exist some common challenges to land use planning at farm level (Fresco 1994:5-7), which include:

1. Diverse land owners – land owners are unique and different, come from various social and cultural backgrounds and hence they are likely to have different approaches and methods to choose a land use.
2. Goals among the stakeholders involved in the planning process are diverse. For example, a landowner might be interested in profit maximization but the government may not allow a certain land use in the interests of conserving the environment.
3. Future expectations – land use planning is a continuous, iterative process which demands minor adjustments as and when needed.
4. Limitations of existing models – current models do not accommodate scale variations and community involvement.

There are commonly two approaches that explain land use decisions by land owners (Mather 1986:26). One approach assumes that the physical factors such as soil type and water availability determine the use of land. The other approach views the land use decision making as a purely economic activity of investing resources and reaping benefits. Land owners make land use decisions and choose crops based on their economic aspirations. Farmers then, evaluate these land use choices based on the past performance (yield levels), neighbouring farmer's advice, market demands, seasonal weather forecasts and government regulations. There are some decision supports systems that help farmers in the process of evaluating various crop choices and then choosing the optimal crop for their farm units. A brief overview of such computer-based decision support systems are presented in the next chapter.

2.6 Needs of farmers

The current research is aimed at farmers of developing countries who often do not have expert agriculture advice from crop advisors. Hence, it is necessary to study the specific goals that motivate land owners and farmers. Basically, farmers would like:

- to understand the potentials and limitations of their farm units' resources
- to discover how the available land resources can be utilized optimally
- to find out, in particular, which specific crop will be most profitable and feasible for the farm unit
- to determine ways to restore land productivity that will lead to conservation of resources for future

Based on these motivations, the basic purpose of land evaluation is to estimate the potential of land to get optimal economic returns by cultivating alternate crops. Farmers who have understood their land potential and who derive maximum benefits from their farm would not be interested in formally evaluating their land units for alternate crops. This "Crop Advisor" expert system is for those farmers and land owners who are contemplating a different land use or crop, and who want to better utilize their farm resources to meet their economic goals.

During the period June 2001 to November 2001, Indian Agribusiness Systems Pty Ltd conducted an information-needs survey (Maru 2003:9-10) across selected districts of three States of India to understand the needs and information requirements of Indian farmers. The study highlighted the fact that most farmers wanted to know the best crop for their land unit considering their land's resources. Others wanted to know such as how to grow crops efficiently and how to market them to obtain the best price. Farmers were also interested in evaluating their farm units to find out feasible new crop choices.

2.7 Summary

Land is the basic necessity for our survival. Land has been exposed to many risks resulting in degradation due to improper management. Land resources need to be evaluated and land uses must be planned for the successful management of land. Different stakeholders involved in the land management arena are motivated by different objectives. To develop a successful land use plan, the knowledge and expertise from various stakeholders must be gathered and negotiated under a common framework. A multi-disciplinary approach is essential for arriving at a consensus among the different stakeholders involved in the land use management. Land evaluation and land use planning are regarded as group activities involving various experts from different disciplines and thus a decision support system that is capable of handling the complexity is needed. The current research proposes to collect knowledge from a single crop expert who is capable of providing multi-disciplinary knowledge rules to build an expert system for developing land use plans at farm level. In the next chapter, a review of existing decision support systems that have been developed and applied in land evaluation and land use planning is presented and discussed.

CHAPTER 3

COMPUTERS IN AGRICULTURAL LAND USE PLANNING

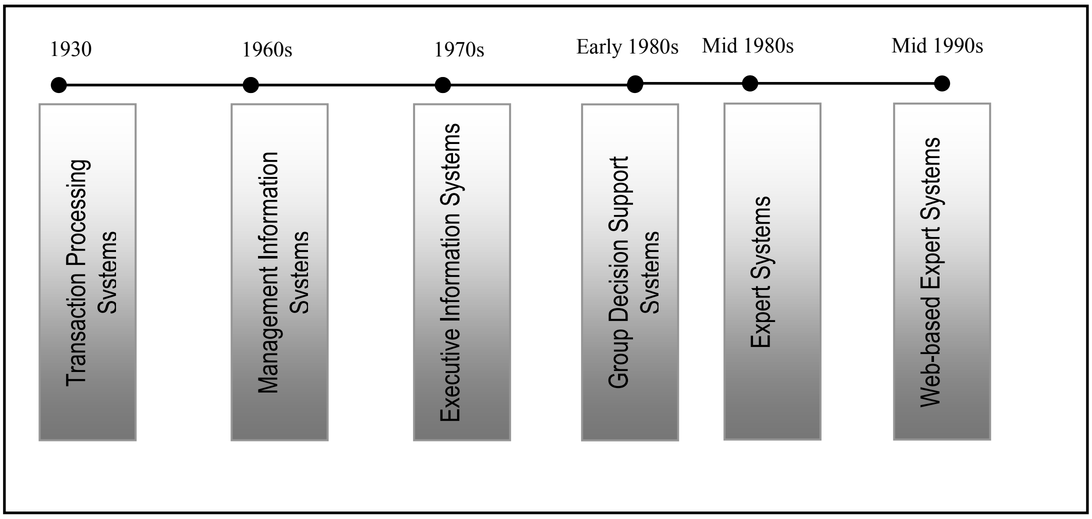
3.1 Introduction

The chapter presents an overview of the application of computers in land evaluation and land use planning. It begins with an historical account of use of computers in decision-making and use of computer-based decision support systems in land use planning. It lists the drawbacks of early decision support systems that are based on algorithmic approach to solve land use problems. The chapter then introduces the expert systems and how it resolves the drawbacks of traditional DSS and discusses about the use of knowledge-based tools and GIS tools in land use planning. Finally, the chapter reviews present decision support systems that combine the Expert Systems and Geographic Information Systems (GIS) technologies.

3.2 Computers in decision support

The use of computers in decision-making dates back to the 1960s (Lucas 1973:22-24). The earliest computer systems were Transaction Processing Systems (TPS) that were used to do repetitive, labour-intensive processes that could be streamlined to reduce costs (Stair 1996:58). Later, Information Systems were developed for digitizing, storing data and retrieving information. Management Information Systems (MIS) made use of these information systems to assist management functions including report preparation, scheduling and planning. The evolution of various technologies adopted in decision support systems is presented in Figure 3.1.

Figure 3.1 Evolution of Computer Systems in Decision Support (adapted from Power 2005)



Decision making involves three stages viz., (i) defining a problem, (ii) developing alternate solutions and (iii) choosing the best solution from those alternatives (Mintzberg, Raisinghani & Theoret 1976:251). An ideal decision support system should help users in these three steps of decision-making to solve a specific problem. Decisions Support Systems have been applied in almost every conceivable field, have embraced every kind of technology, and have grown stronger over the years (Beynon, Rasmequan & Russ 2002:127). With other complementary technologies, decision support systems have been applied in planning and management of resources. Land use planning is one such area in which they have been found a successful application.

3.3 Computers in land use planning

The process of land use planning has become simpler and more refined with the advent of computers. Many organizations developed information systems to store, analyze, and retrieve stored information for helping in day-to-day decision-making (Lucas 1973:22-24). These information systems helped decision-makers to solve resource allocation problems better and faster. However, these systems simply stored the data and facts which supported decision makers. Decision makers were supplied with critical information and patterns that exist in the data for simplifying the decision-making process. Also, each information system was a stand-alone computer system, which made the interaction process difficult in case of a problem which could benefit from integration of information from multiple scientific disciplines.

Later, semi-automated decision support systems were introduced which used specific algorithms for solving problems. Semi-automated decision support systems presented decision makers with various alternate choices and recommending the best among them. Numerous decision support systems have been developed for land evaluation and land use planning and they have been reported in the literature. The more significant are the Field level GIS (FLEGIS) (Runquist, Zhang & Taylor 2001; Zhu, Xuan & Dale 2001), the spatial decision support system (SDSS) (Matthews, Sibbald & Craw 1999), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Malczewski 1996) and the Multiple-Criteria Decision-Making model (MCDM) DSS (Pereira & Duckstein 1993). These consider multiple factors to support problem-solving in land use decision making. A notable recent development is the Spatial Decision Support System (SDSS) in Kenya (Ochola & Kerkides 2004) which carries out land quality assessment based on a number of factors such as land holding, farm labour availability and access to agricultural extension services as well as selected socio-economic factors. However, such decision support systems could not match the decision-making process of a human expert and had some inherent limitations. These decision-support systems required a set of predefined input datasets to begin their analysis. Without providing such inputs in a proper required format, the system could not begin the analysis. After getting inputs from users, with a step-by-step approach, as dictated by algorithms, the decision support systems proceeded to analyze the input data to reach conclusions. Often the knowledge about solving the problem was represented in the DSS's algorithm based on a multiple-criteria decision-making model (Laaribi, Chevallier & Martel 1996:354). The system analyzed the input information and produced a better land use plan after evaluating the land capabilities and eliminating unfeasible crop choices for a farm unit. The quality of the results of land evaluation and land use decisions depended on the efficiency of algorithms. The algorithms were embedded within the decision support systems and hence a change in algorithm needed redevelopment of the decision support systems. New algorithms, and hence new decision support systems, were developed in order to improve the quality of land use decisions. The following section lists the drawbacks of such traditional decision support systems that depend on algorithms that are difficult to change without modifying the entire software application.

3.4 Disadvantages of traditional approaches

The inherent disadvantages associated with traditional algorithmic DSS can be listed as follows:

i) The algorithm is directly embedded into the application i.e., the knowledge of problem-solving is within the program (software). The software needs to be modified or redeveloped if the knowledge base needs to be updated. In other words, the criteria for solving the problem cannot be separated from the software program.

ii) Modifications of the criteria are difficult as it requires programming expertise or knowledge about the models and software tools used in DSS.

iii) Algorithmic approach is fixed and rigid as it is not flexible enough to modify on-the-run.

iv) Any new alternative solutions required the entire application or software to be re-written.

v) Algorithmic approach controls the flow of problem solving by step-by-step, linear approach rather than quick, intuitive approach. For any given inputs, the algorithmic approach would follow the same steps and hence take the same amount of time for every run.

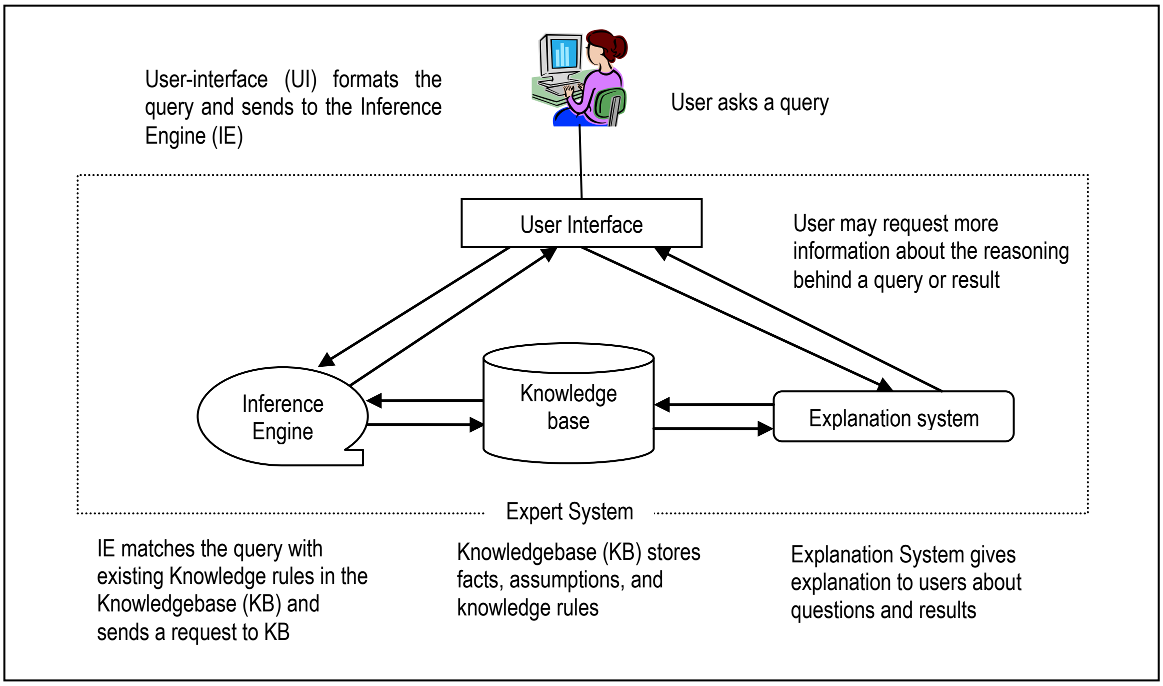
Though there are many disadvantages found in a rigid, fixed approach it is not humanly possible to solve a problem which has no predefined number of variables. In any decision-making problem, all the variables which affect a decision are not taken into account. Instead, the ones that are considered sufficient to solve the problem are used. In a classical decision-making problem, it is often difficult to predict the number of variables involved in advance (Hale & Whitlam 1997:138). The number of factors (variables) may decrease or increase depending on each input case. Each case may use different number of factors (variables) depending on its complexity. The user may not have inputs for all the variables (or the user may not wish to use all variables) required by the program. Hence, it is sensible to search for an approach which accommodates such flexibility. The decision making model should function even if the user omits some variables from the set used by the decision support system. It would be an added advantage if the decision support system facilitates adding of new variables to it based on which the problem can be solved.

In short, land evaluation and land use planning require a program which can handle these uncertainties (data availability) and simple enough to be modified by anyone without the need to rewrite programs and software. Despite many improvements in algorithms, tools and user-interfaces, the implementation and usability of DSS had been moderate due to the lack of a human centric, empirical approach to problem-solving (Beynon, Rasmequan & Russ 2002:127). There were no provisions to include such heuristic knowledge into the traditional decision support systems. The DSS followed a machine-like approach rather than the human-like, cognitive approach. In addition, these systems were found to be rigid and the criteria required for the decision-making process were coded directly in the software program. Hence, any modification needed alteration of the entire program. These shortcomings led researchers to conceive a system where the knowledge base (criteria used to solve a problem) could be kept separately, which would enable modifying the knowledge base without disturbing the whole structure.

3.5 Expert systems

In the early 1980s, the science of artificial intelligence began to develop knowledge-based expert decision support systems (or simply, expert systems) which could use not only scientific knowledge but also cognitive knowledge to solve some simple medical diagnostic problems (Kent, Hall & Williams 2000:115). Although the problems solved were simple, expert systems became invaluable tools in automating certain laborious, well-structured tasks such as diagnosing a disease by following a set of symptoms. With acquired in-depth knowledge and expertise in a narrow domain, expert systems can be engineered to deliver decisions and recommendations (suggestions) as easily as humans can. Like a human expert, these systems rely on an extensive knowledge base to solve domain-specific problems (Jackson 1999:2). A typical knowledge base stores information and knowledge in the form of rules and it is independent from other program modules (see section 3.6 for more details). Expert systems keep the rules used in decision-making (called as knowledge base) separate from the program which controls the flow (the inference engine) -see Figure 3.2. Expert Systems utilize the derived human intelligence (knowledge) to imitate human experts in solving a problem. Expert systems are usually suited for land evaluation and land use planning problems, as this field requires comprehensive, up-to-date knowledge from various domains involving a variety of information sources. Since expert systems work on a continuously growing knowledge base, they can behave similarly to a human expert in solving multiple problems in a domain.

Figure 3.2 Components of a typical Expert System (adapted from Luger & Stubblefield 1989:294)



Most of the expert systems also have an explanation module, which can give an explanation for arriving at a particular decision. Another advantage with the ES is that the knowledge base can be created, expanded and edited by anyone without disturbing the program module. Expert systems can work even if some factors are omitted by the user as opposed to the traditional decision support systems which will not solve a problem unless all the necessary factors are provided by the user.

3.6 Components of an expert system

A typical knowledge-based expert system essentially should possess three components (Figure 3.2) viz.,

(i) **Knowledge base** which contains the necessary rules and procedure for solving a problem

(ii) **Inference engine** which controls the information flow between the user interface to knowledge base and

(iii) **User interface** which collects inputs from the user and displays outputs to the user.

3.6.1 Knowledge base

The knowledge base is the heart of a knowledge-based system (KBS). It records the factual and causal knowledge from human experience and scientific studies in more than one way. The knowledge base contains a collection of rules and assertions on land evaluation and crop suitability. The knowledge rules used in the research are supplied by the South Australian Department of Land, Water and Biodiversity Conservation (DWLBC). The validation of knowledge rules is an important step in building the knowledge base. The knowledge rules used in this research have been thoroughly cross-checked for consistency across the entire knowledge base with assistance from a crop expert at DWLBC. In case of more than one expert or expert knowledge bases, this process can become tedious as there are more chances of disagreements among the various rules. For example, a rule may be favoring a certain crop choice but another rule may completely omit that choice. In this case, priorities and confidence levels must be set for each knowledge rule to ascertain which rule should take precedence in case of a rule disagreement. This is similar to the procedure giving weightings (prioritizing) to the factors and rules involved in a multi-criteria decision making problem. Prioritizing is ranking of factors on their significance towards the overall decision making process. Confidence levels are specifically developed for heuristic rules which come from human experience. This is because human perceptions and notions resulting from experience may vary from person to person. So, for each rule, a confidence level needs to be specified to ascertain the rule's consistency. Confidence level for a rule can vary from 0 to 100 on a scale of consistency measure, where 0 indicates absolute unsurety and 100 indicates absolute surety. Ideally, a threshold confidence level can be set for each factor to make a rule active, and this threshold depends on the nature of factors and the importance of each factor in problem solving. For instance, if the threshold confidence level for a factor is set at 70, it is necessary that a rule should have higher confidence value (surety) to become active. If not, that particular rule will be ignored in the problem solving.

3.6.2 Inference engine

When the user inputs a set of land qualities or land characteristics, the inference engine matches these with the existing rules in the knowledge base and suggests a crop most suited (optimal) to that particular land unit. It acts as an interpreter between the knowledge base and the user interface. The inference engine receives each incoming query (problem) and matches it with a similar pattern in the existing knowledge-base to prepare a solution (answer) for that query. In other words, the inference engine does the reasoning and then provides explanations for arriving at a particular solution.

3.6.3 User interface

This is the most important component of the expert system from a user's point of view. It should act as an easy-to-use interface to get inputs from users and provide outputs to users.

The expert systems of the 1970s were specifically developed for a single domain problem, for example, MYCIN (Shortliffe et al. 1975) enabled medical diagnosis and PROSPECTOR (Duda, Gaschnig & Hart 1979) helped in mineral prospecting. Slowly, the trend of ES applications shifted from discipline-specific (solving all problems in a domain) to problem-specific (solving a problem using multi-disciplinary knowledge) (Shu-Hsien Liao 2005:99). Some complex problems like land evaluation and land use planning demand multi-domain knowledge and this led to the development of multi-domain expert systems. Multi-domain expert systems require knowledge from more than one domain and generally used to solve multi-disciplinary problems (Chew, Tan & Murphy 1995:177).

In the real world, environmental, socio-economic and demographic phenomena occur in a spatial context. Decision making associated with these phenomena is regarded as "spatial" as it is a process of "solving spatial problems using spatial means to achieve desired spatial ends" (Erik De Man, 1991 quoted in Chen & Gold 1992:2). Land management problems are essentially spatial in nature, in that they involve observations (measurements) from a geographical area. The management decision-making is dealt with by considering the land as discrete, spatial units. Recent years have seen the rise of GIS (Geographic Information System) tools as an effective way to manage spatial information in a digital environment. Hence, most of the decision support systems in the land management domain are spatial decision support systems (SDSS). They simplify the implementation process by producing results in the form of scaled maps which can be referred to during ground surveys. The combined approach integrating heuristic knowledge bases in a spatial environment helps land managers in planning and decision-making. They integrate the spatial modelling capabilities of a typical GIS and reasoning ability of expert systems.

3.7 Importance of GIS

Geographic Information Systems (GIS) are a set of tools which capture, store, analyze and present geographically referenced spatial data (Burrough 1992:1). To assess and manage resources, appropriate tools are needed to understand and visualize their inter-relationships. GIS tools help in modelling and visualizing complex relationships in order to solve a spatial problem. This involves an integration of social expectations and ecological capabilities and minimizing the differences between resource demand and availability. While the satellite borne sensors and mapping technologies help in providing inputs, GIS tools have been useful in breaking down the “spatial complexities” that exist between various natural and man-made phenomena on the Earth's surface (Ponnusamy & Gowda 2002).

The real world can be categorized and its entities including natural, demographic, socio-economic information and infrastructure facilities and services can be mapped into several spatial datasets. The integration of this diverse datasets within a framework needs powerful tools that can manage a huge amount of spatial information. It demands consistency across the datasets and requires an effective matching of entities based on their geographic locations. GIS tools permit a synergy between various conventional datasets, computerized databases and information from diverse disciplines including statistics, cartography, photogrammetry and remote sensing (Ponnusamy & Gowda 2002). A successful approach to land evaluation invariably requires data, information and knowledge from various sources to be integrated. GIS, with its associated tools, is capable of performing integrated analyses to transform the datasets into the required information for land evaluation. Expert systems use GIS tools to handle these spatial datasets and by employing the knowledge rules and methods contained in their knowledge-bases, they go hand-in-hand to solve problems like land evaluation, environment impact assessment and site suitability studies. Many instances of expert systems and GIS integrations can be found from the literature, and the next section reviews some integrated systems that have been developed to solve land evaluation and land use planning problems.

3.8 Expert systems and GIS in agricultural land use planning

From an extensive survey of literature since 1986, at least 30 decision support systems can be found that combine Expert System and Geographic Information System tools to solve the problem of land evaluation and land use planning. Of these 30 decision support systems, only seven are actively used in the decision making processes and they are presented in Table 4.1. There are some specific land use planning expert systems that have used multi-domain knowledge bases to deliver land use decisions and recommendations. The majority of these expert systems followed the theoretical framework for land evaluation outlined by the Food and Agriculture Organisation (FAO 1976).

Table 4.1 List of Expert Systems used in Land Evaluation and Land Use Planning

NAME	ES	GIS	Land Evaluation (LE) OR Land Use Planing (LUP)	COMMENTS	Farm level Decisions?
MicroLEIS	✓	✓	Both	– web enabled – serves a specific region – little use by farming community	No. Can be used as a guide.
LEIGIS	✓	✓	LE	– physical LE, limited economic factors – social, economic, climate factors need to be included – considers 5 crops	Yes.
ILUDSS, Scotland	✓	✓		– soil and water conservation – cost estimation for development	Yes.
EGIS, Thailand	✓	✓	Both?	– uses ALES shell	No.
CRIES, Kenya	✓		LE	– uses ALES shell	No.
PNGLES, Papua New Guniea	✓		LE	– uses ALES shell	No.
LEV-CET, Ethiopia	✓		LE	– uses ALES shell 3 crops	Yes.

The Automated Land Evaluation System (ALES) is a customizable ES shell that can be developed into an expert system to the user's requirements (Rossiter 1996:3). Kenya's Comprehensive Resource Inventory and Evaluation System (CRIES) (CRIES 1983), Papua New Guinea Land Evaluation Systems (PNGLES) (Venema & Daink 1992) and the Land Evaluation system for Central Ethiopia (LEV-CET) (Yizengaw & Verheye 1995) are few expert systems developed using ALES expert system shell. However, all of these systems relied heavily upon the physical land evaluation, neglecting social and economic factors. Socio-economic conditions of farmers such as farmer's skills, size of land holding, current market price for a crop, its market demand, neighbouring land uses and government policies and regulations have a considerable effect on land use decisions. Only a few land use expert systems, such as the Islay Land Use Decision Support System (ILUDSS) (Zhu, Xuan, Aspinall & Healey 1996), the Land Evaluation using an Intelligent Geographical Information System (LEIGIS) (Kalogirou 2002) and the Mediterranean Land Evaluation Information System (MicroLESS) (Rosa 2004) consider economic factors, and then only in a limited way.

More significantly, none of these expert systems took current knowledge (market price, demand for a crop produce, weather forecast, government policies) into consideration. Instead, most of these expert systems have a static knowledge base which does not take this dynamic information. It is however agreed that it is impossible to preconceive all the factors necessary for a decision-making problem. So, provisions need to be made to incorporate new, additional factors into the decision support system. At least a software framework needs to be developed which allows addition of new factors. Further, the reported expert systems were mono-objective, conceived to solve a specific land use problem such as finding land units suited for growing a particular crop rather than attempting to find a best crop for a land unit considering available resources and crop choices.

While such reviews are important from a systems perspective, Bacic, Rossiter & Bregt (2003) investigated the reasons for failure of land evaluation systems in a case study in Brazil. The primary shortfalls of land evaluation programs as identified by the survey respondents included the failure to assess crop suitability with factors such as weather, yields, profits and market (financial) analysis, absence of social analysis (needs and motivations of users), and inadequate choices for land use alternatives (not providing multiple land use options). These deficiencies could have been avoided with a demand-driven approach, by considering the true needs and opportunities of the users. Hence, finding the needs and expectations of users of the proposed expert system becomes a critical, an essential step. Though, current research never attempted to find the needs and expectations of the users directly, it used secondary sources (See section **Error! Reference source not found.**) to understand their needs. It aims to build a knowledge-based expert system which would overcome some of the shortfalls of existing expert systems that are used in farm level land evaluation that help in choosing optimal crop choices.

3.9 Summary

The role of decision support systems which use algorithms is very limited in land evaluation and land use planning. Expert systems approach the problem by emulating human experts and having a continuously growing knowledge base. The existing expert systems are limited in real-world application as they consider limited factors, suggest few land use options and do not consider socio-economic and local factors. There is a need for a comprehensive agriculture land use expert system, which could help farmers with a holistic approach, served by multi-disciplinary knowledge bases to assist land owners in deciding a suitable crop. There is also a need to know what the users' expectations are and provide power in the hand of users to choose between alternative crop choices among the suitable ones. The next chapter outlines the various frameworks used in land evaluation and land use planning and presents current research framework.

CHAPTER 4
FRAMEWORK FOR KNOWLEDGE-BASED SPATIAL DECISION SUPPORT SYSTEMS

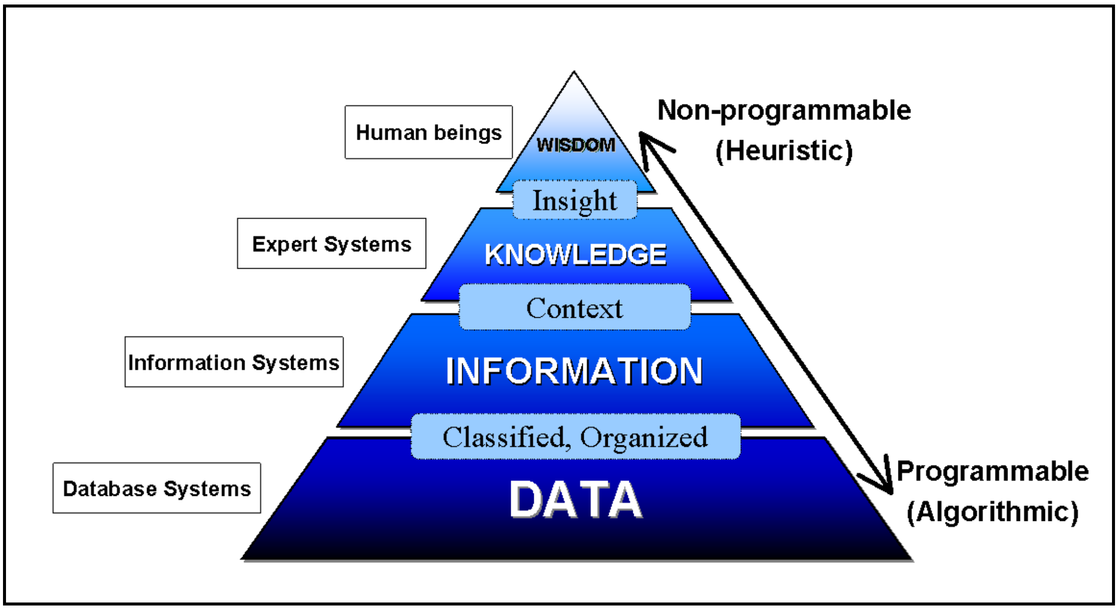
4.1 Introduction

This chapter discusses the concept of data, information and knowledge and explores the knowledge flow in agriculture. It lists the types of knowledge and proposes a framework for acquiring knowledge from human experts. The chapter reviews the various frameworks that have been used in designing land evaluation and land use planning systems and then outlines the concepts and frameworks adopted in the current research. It argues the advantages of a knowledge-based framework over other frameworks.

4.2 Data, information and knowledge

If data can be defined as a collection of discrete, unorganized facts or observations, information will refer to the processed data aggregated in a meaningful way that provides additional value (Awad & Ghaziri 2004:36). Knowledge will then refer to the information with a context that is ready for usability for decision-making (Spender 2005:135). Knowledge can be a collection of rules, guiding principles, events and measures that are contextual to a problem. With the help of knowledge, snippets of data and information can be aggregated, organized and presented as a solution to the problem in hand. The relationship between data, information and knowledge can be depicted in an illustrative form (Figure 4.1). This relation was first proposed in the literature as a Data-Information-Knowledge-Wisdom (DIKW) hierarchy model (Ackoff 1989 quoted in Spender 2005:135).

Figure 4.1. Knowledge Pyramid (adapted from Awad & Ghaziri 2004:41)



As shown in Figure 4.1, data forms the fundamental base for deriving information, knowledge and wisdom. Computers are useful in handling data and information and knowledge to some extent, whereas, attaining or realising wisdom is still the sole territory of human beings. Database management systems are specialized in managing data. Information systems are useful in classifying and organizing data in a coherent, meaningful way. Knowledge can be derived by collating various pieces of information with a collection of rules and procedures that have similar (common) context. Expert systems are useful in collecting, storing, processing and delivering this knowledge. At the bottom-end of the pyramid remains the data which can be programmed algorithmically. As we move to top, we find knowledge and wisdom that are non-algorithmic and heuristic in nature.

Knowledge is primarily gained through learning by experience, studying and validating information gathered from many sources. Awad & Ghaziri (2004:42-47) classify knowledge into categories based on the ease of access, method of accruing and ease of programming. They can be summarized into two types viz., (i) procedural, shallow knowledge and (ii) episodical, deep knowledge. While it is easy to acquire and use the first type of knowledge, it is often difficult to extract the second type, which is tacit and deeply embedded in human minds and which cannot be easily expressed in words. Such form of tacit knowledge is very useful in disciplines of medicine and engineering which require qualitative advices and opinions from experts (Nikolopoulos 1997:1). Expert systems help in collecting, storing, manipulating these type of knowledge for decision-making.

4.3 Knowledge in agriculture

One of the earliest definitions of agriculture (Norton 1855:2-3) describes it as a mix of art and science. Agriculture is the art, science and business of cultivation by raising crops and livestock (Ramharacksingh 2000:3). It is essentially a scientific process, but can become an art when production resources are constrained as in the case of rain-fed farming. The knowledge of farming comes from an understanding of different ecological factors that directly or indirectly influence plants and animal growth (Piper & Soule 1992:79). Farmers who interact with these factors have acquired this knowledge through their life time experiences. This knowledge is very vital and how it flows from one person to other forms an interesting study. During this flow, knowledge is validated, updated, generalized or even modified to suit regional variations. The knowledge flow in agriculture is complex but can be broadly categorized into two categories (Arunachalam, 2002):

(i) Knowledge flow from farmers to scientists (as a result of ground observations and field practices)

(ii) Knowledge flow from scientists to farmers (from theories, experiments and cross-cultural studies)

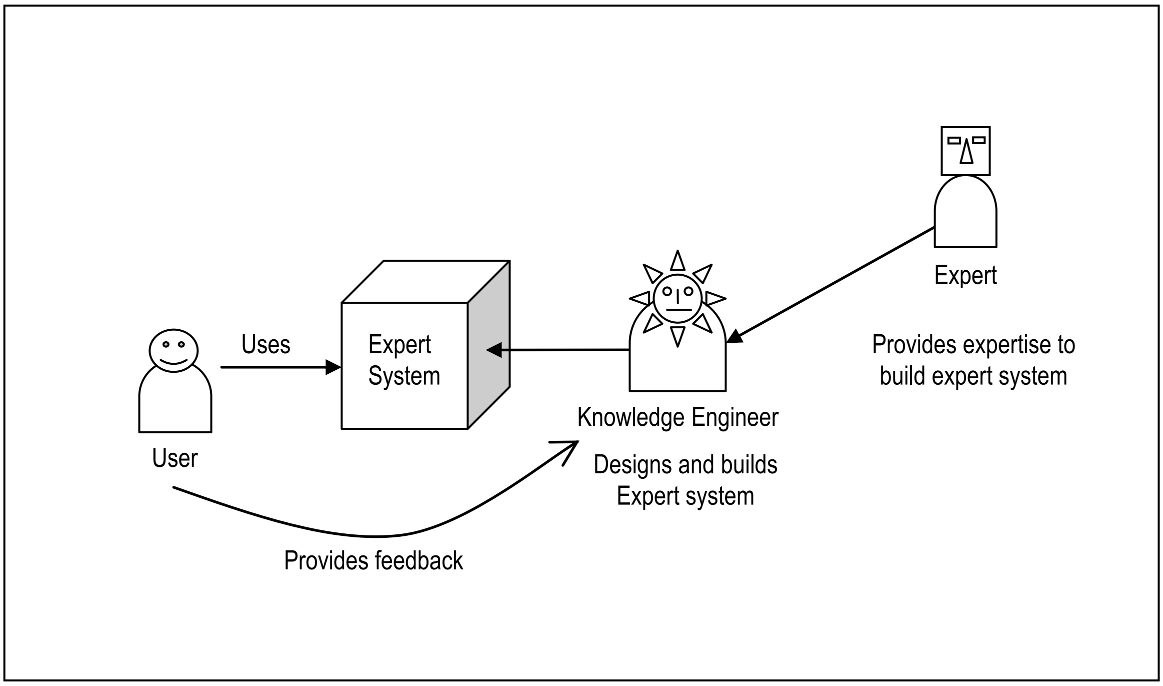
To these, a third and important category of knowledge flow can be added - knowledge flow between farmers (traditional knowledge, local, empirical knowledge). This type of knowledge is used by farmers widely in their day-to-day operations and practice but rarely gets published in scientific literature.

The challenge for any expert system is to integrate all these types of knowledge into a system to help in solving agricultural land use problems. While the first two categories of knowledge can be readily found in the form of text-books and reports, the third category which deals with empirical knowledge gained by farmers and crop advisor (who closely work at the farm level) can be acquired from them.

4.4 Framework for knowledge acquisition

Acquiring knowledge is an important yet daunting task for a knowledge engineer – a person who designs and builds a knowledge-based system (See Figure 4.2). The knowledge engineer interacts with experts to gather the knowledge required to solve the problem addressed by the expert system. The user uses the expert system and provides much needed feedback to the knowledge engineer who uses them to improve the expert system. As the current research is time-constrained; knowledge is not acquired directly from the farmers. Instead, the research relies on the secondary knowledge gained by land evaluators and crop experts who interact with these farmers. Using this knowledge, current research attempts to construct a working prototype for evaluating land resources. The success of a knowledge-based expert system will lie in the accuracy of its knowledge base. The limited knowledge base used in developing the prototype may not be sufficient to provide real-world solutions, but it aims to set a framework which can be improved further at a later stage.

Figure 4.2 Figure showing various users associated with expert systems (Refer to page 5 for definition of terms)



4.5 Framework for knowledge-based spatial decision support system

Land management problems such as land evaluation, land use planning and site selection demand knowledge from multiple disciplines. Often these problems are complex as the factors associated with them and their inter-relations are difficult to measure and model. Experts who solve such problems may need to accommodate for incomplete, inaccurate or fuzzy datasets. Hence, these problems need a flexible, knowledge-based, heuristic approach as opposed to algorithmic, rigid methods of problem-solving. The dual objective of developing a knowledge-based system is to acquire human expertise about a problem domain and to use it to mimic a human approach to solve the problem.

In a detailed review, Zhu, Xuan, Aspinall and Healey (1996:279-301) argued that users experienced difficulty in operating these hybrid systems due to their unfriendliness. User interventions were required for exchanging data or information and transferring controls among those ES and GIS i.e., a smooth inter-operability between ES and GIS was missing. Users not only needed to know about the problem-solving methods but also the intricacies of ES and GIS tools and procedures. Combining the knowledge-based approach with spatial decision support tools, Zhu et al (1996:281) proposed an integrated "Knowledge-based Spatial Decision Support System" (KBSDSS) for assisting planners in strategic land use planning. A KBSDSS incorporates spatial, quantitative, and qualitative modelling capabilities for problem-solving (Zhu, Xuan , Healey & Aspinall 1998:37). It integrates components such as domain knowledge bases (for solving problems), model knowledge bases (for formulating approaches) with problem processor and back end systems containing GIS and expert systems (rule bases). A query processing system helps in receiving queries from users and displaying results back to users after analysis. A modelling subsystem allows users to wither choose an existing model or design their own model of problem-solving.

Developing such a tightly integrated system costs money and time. With both these resources restricted, it is proposed in this present research to keep GIS operations separate from the expert system development. The spatial analyses of datasets will be carried out in a GIS and converted into a form which is ready-to-use by the proposed expert system.

4.6 Frameworks for land evaluation

Land evaluation is considered as a complex, multi-faceted problem. Attempts have been made since 1950s to develop a satisfactory, universal land evaluation model (Rossiter, 1996:2-3). A comparative evaluation and a detailed review of different land evaluation frameworks were presented by Rossiter (1996). Prior to the land evaluation frameworks released by Food and Agriculture Organisation (FAO 1976, 1983, 1984, 1985 and 1991), land evaluation programs had some common shortfalls. They gave much importance to physical land evaluation and ignored socio-economic aspects of land use. They tried to classify land for a generic land use which is an inappropriate method of evaluation as opposed to a detailed, local evaluation of land attributes for specific land use purposes (Diepen et al. 1991:153). To alleviate these shortcomings, scientists at the United Nations Food and Agriculture Organisation (FAO) worked together to prepare a common framework - "Framework for Land Evaluation"- (FAO 1976), which is considered to be a milestone in the discipline of land evaluation (Beek 1981 quoted in McKenzie 1991:13). This framework provided a general overview of land evaluation methodology outlining important considerations in designing a methodology for land evaluation suited to local conditions. It provides definitions, a description of land qualities and guidelines for physical and economic land evaluation. The radical changes reflected in the FAO framework are the inclusion of socio-economic and local political factors in the land evaluation process, assessment of land with respect to specific land use types, a multi-disciplinary approach to land evaluation, setting priorities for environmentally sustainable land uses and providing alternative land use options for users. Moreover, the FAO framework is easily modifiable to adapt different implementation methods to different local conditions.

The framework developed by FAO comprises key terms and their definitions such as land characteristic, land quality, land utilization type and land use requirement (FAO 1976:9-12). Land characteristic is a direct measure of simple attributes of the land that can be directly observed in a routine survey. For example, soil texture or pH of the soil. Land quality is a complex attribute that can be derived by combining one or more land characteristics. It could be a qualitative or quantitative derivative of land characteristics. For example, a land quality named soil acidity is derived from pH, calcium, aluminium measurements in the surface and deep soil. Land utilization type is a type of broad land use category. For example, horticulture crops, dry land farming or intensive (irrigated) farming represent different land utilization types. Combinations of certain land qualities form the ability of the land to fulfill specific land use requirements. Land use requirements are the criteria required by certain land use (or a crop in particular) for successful implementation of a land utilization type. For example, the criteria (conditions) that are required by intensive farming may be different from dry land farming. Further, the FAO (FAO 1994:15) framework outlines the steps involved in executing a land evaluation which is briefly presented below:

i) Identification of decision-makers, their objectives and means of implementation
ii) Definition of the spatial entities that need to be evaluated
iii) Definition of the land utilization types to be evaluated
iv) Definition of the land utilization types in terms of land use requirements
v) Translation of the land use requirements in terms of land qualities and land characteristics

vi) Building computer models for evaluation

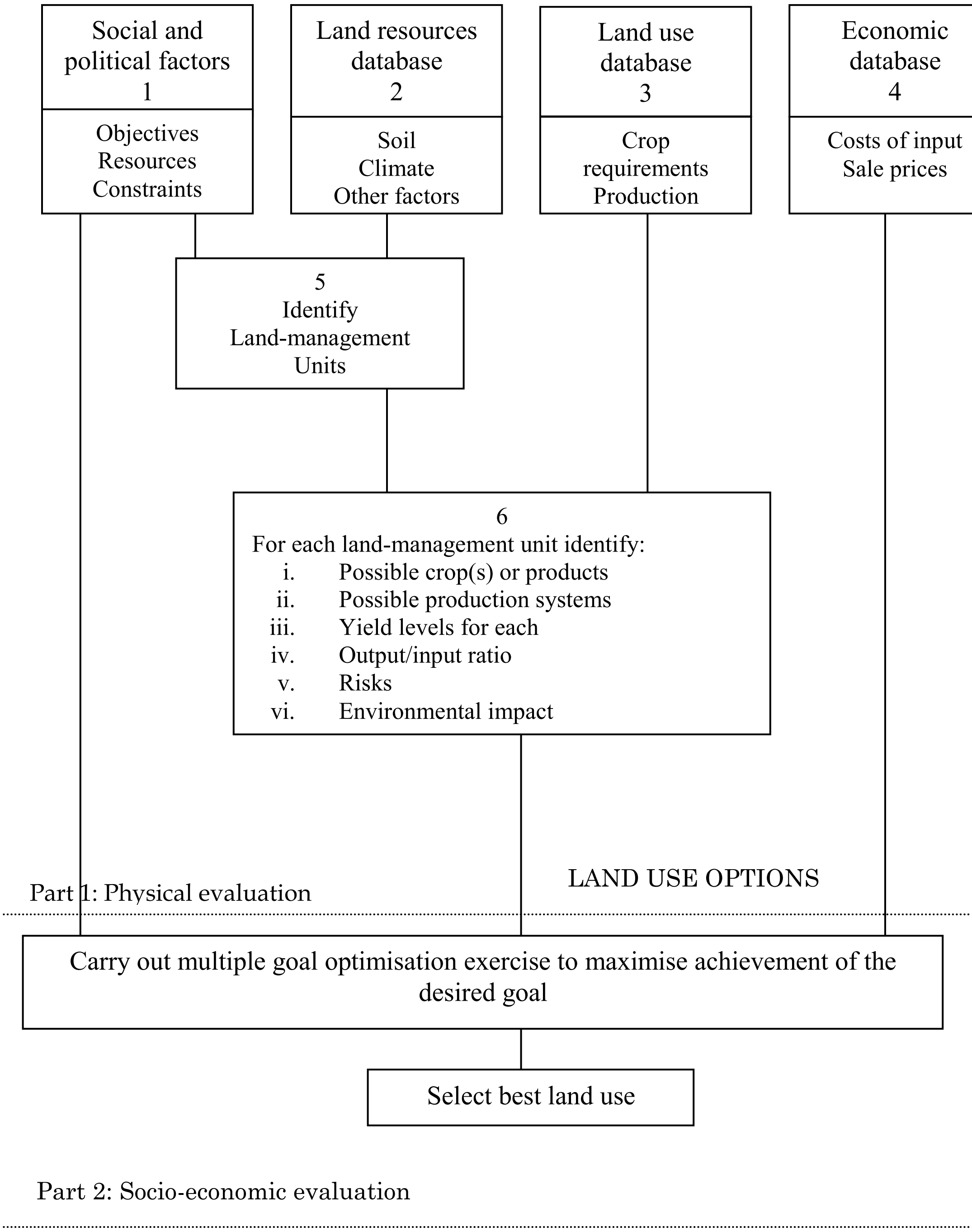
vii) Computing and calibrating the results

viii) Presentation and Implementation of results

4.7 Current research framework

The FAO framework is simple and broadly aids at developing a land evaluation model. Hence, it has been adapted in the current research. The FAO model is illustrated in Figure 4.3. It includes climate factors, economic, social and political factors which influence the crop selection process. This procedure also takes environment risk (if any) associated with each land use choice (specific crop), yield levels and anticipated market demand for a crop produce. While the physical land evaluation (Part 1 in Figure 4.3) process would eliminate the impossible land use choices (or specific crop types) for a land unit, the socio-economic evaluation (Part 2 in Figure 4.3) would discard land use choices which are uneconomical or not feasible due to other social or political reasons. In the end, selecting the best land use always rests with the land owner, the user of the model, who will be usually presented with land use choices in a descending order from most suitable to least suitable. Hence, it is also possible to provide remedial measures or explanations in order to switch to a second choice in case the user is not willing to settle for the first crop suggested by the system.

Figure 4.3. Simplified sequence for making decisions about the best use for land (FAO 1994:15)



Rossiter (1996) classifies land evaluation models into three major categories viz., (i) non-spatial models that do not consider actual location of a land unit (ii) spatial models that consider geographical surroundings (iii) multi-area land distribution model which achieves an optimal plan. The first two categories are further classified into four sub-categories each based on whether the resource bases are considered static or dynamic and if the land suitability is static or dynamic. The current research model is classified as spatial based on a dynamic resource base to provide dynamic land suitability. The model considers geographical location of a land unit for evaluation, the rainfall distribution occurring in a farm unit. The model evaluates land on a dynamic basis i.e., the suitability of a land unit for a particular land use varies with time. Whenever land is evaluated, current weather, market value and government regulation factors will be taken into account. In order to build a successful decision support system, it is essential to know how people make agriculture decisions in the real-world. Also, it is necessary to identify the specific decision criteria used by them in the whole process of decision-making. Only after a thorough understanding of the current decision-making process, will it be possible to suggest improvements.

4.8 Summary

The land use evaluation process is a complex process which demands knowledge and expertise from many disciplinary experts. Land use evaluation and planning problems require integration of datasets from various sources using GIS. Expert systems are useful in gathering the knowledge rules and methods of operation from human land use experts. The proposed research utilizes FAO framework in solving the land evaluation problem. It aims to give equal emphasis to physical, economic, social and political factors associated with land. This approach is significantly different from the traditional ones which require the necessary information and knowledge beforehand. Farmers or crop advisors use an ad-hoc approach to solve such land evaluation problems. The knowledge can be from variety of sources that are related to the planning objectives.

CHAPTER 5
LAND EVALUATION AND CROP SUITABILITY ANALYSIS

5.1 Introduction

The aim of this chapter is to present different approaches to land evaluation and to find out an apt method for evaluating land which can accommodate different type of knowledge types. The chapter lists the motivations and needs of farmers who would use this expert system and methodology adopted by crop advisors. The factors used in crop suitability analysis and their relative importance and two stages involved in the analysis are presented.

5.2 Different approaches to land evaluation

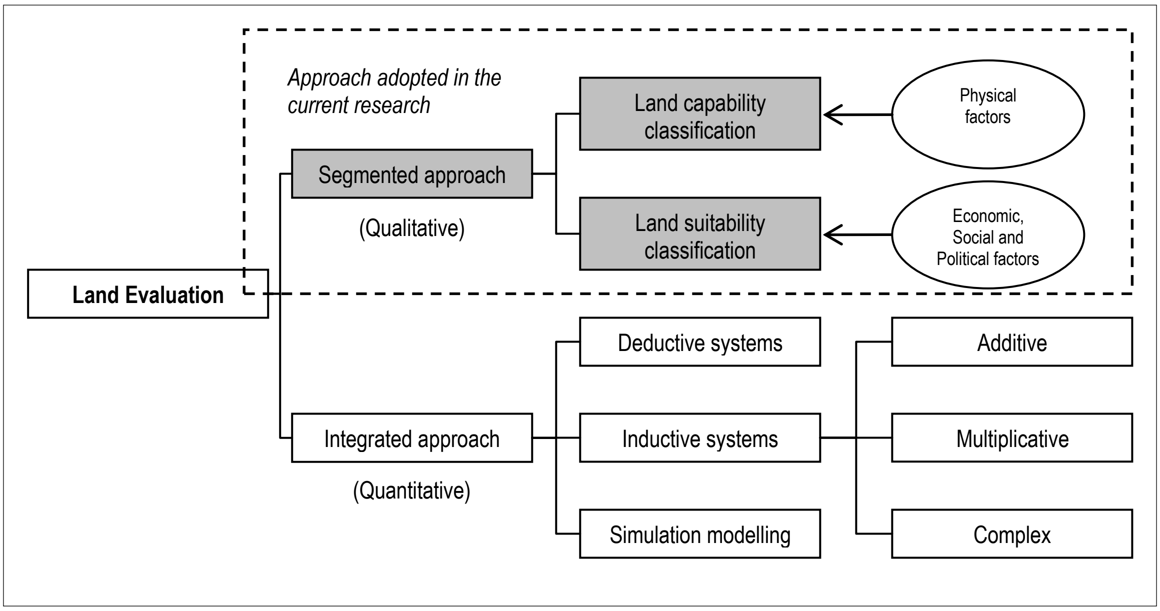
Generic approaches to land evaluation are discussed extensively in the literature (Dent and Young 1981, McRae and Burnham 1981, McKenzie 1991). The adequacy of different methods has to be judged in terms of their capability to support whole farm planning or farm level agricultural land use planning. McRae and Burnham (1981:2-4) classified land evaluation methods into two major categories, direct and indirect. The direct method is site-specific and involves choosing a land use for a land unit and documenting the changes thereby adopting a better land use next time. The indirect land evaluation methods are based on the assumption that certain land characteristics support a specific land use successfully, and by carefully observing and comparing land characteristics, similar land units suitable for that land use can be predicted. Dent and Young (1981:119-120) classified land evaluation approaches into three types based on the results they produce. They are (i) qualitative, (ii) quantitative physical and (iii) quantitative economic methods of land evaluation. A qualitative land evaluation method classifies land units on a relative scale of suitability such as “Highly Suitable”, “Moderately Suitable” or “Not Suitable” for a specific type of land use. This kind of evaluation is more generalized as the physical, social and economic factors are not exactly quantified in numerical terms; hence, it is of little value to land owners and farmers as they would have already known by their experiences. However, qualitative evaluation plays an essential role in estimating land suitability and classifying land units at a regional level and it is very helpful for planners and decision-makers. Alternatively, a quantitative physical evaluation method takes numerical estimates of production inputs and outputs of farming into consideration while evaluating a farm unit. The factors such as farm size, crop yields, and fertilizer inputs are quantified for each crop type and the crop which gives maximum economic returns is selected as the most suitable crop for the farm unit. It is carried out as a precursor to economic evaluation. The third method, quantitative economic land evaluation adds market factors in terms of profit and loss, for each kind of land use or crop choice. In this method, environmental, social and political factors are combined with economic data as a basis for decision-making. Economic land evaluation is usually carried out before the decisions of land purchases are made and it forms an essential step in a project management process.

McKenzie (1991:9-13) classifies the approaches to land evaluation into four types based on their scientific measure, ranging from the least scientific, "trial and error", to more complex method such as "process modelling". The four types include trial and error methods, empirical methods that rely on transfer-by-analogy, semi-empirical methods and process modelling methods. Trial and error method of land evaluation is the oldest approach and it is based on correcting and improving on the past experiences and mistakes (McKenzie 1991:10). This approach has been widely practised and does not need any scientific information. It consumes a great deal of time and often it is risky, especially when new land units are tried for the first time or when new, untried land use types are introduced in a region. In the past, many programs used the trial and error method of evaluation as scientific soil survey results were lacking. Another popular approach is the "empirical land evaluation" method which is based on "transfer-by-analogy" (McKenzie 1991:10) that is similar to the indirect land evaluation method observed by McRae & Burnham (1981:2-4). This is based on the assumption that if a particular land unit is capable of supporting a specific land use, by analogy, other land units which have similar properties should also support that particular land use. The success and reliability of this method depends on how well the classification methods interpret the analogy between those land units. Physical measurements such as soil type, texture and other morphological factors are useful in categorizing the land types and thereby predicting the land capability. However, such physical measurements are difficult to measure accurately and do not exactly correlate with the land capability classes. These shortcomings led land resource scientists to develop a semi-empirical approach to land evaluation (McKenzie 1991:11). In this semi-empirical approach, a land unit's capability to sustain a land use is evaluated by mapping and assessing soil and land qualities through ground surveys. The most limiting factor determines the land suitability to support a land use. The reliability of such method of approach is based on the understanding of physical processes that govern land management process. Finally, "the best theoretical approach to land evaluation", (McKenzie 1991:12) the process modelling approach, attempts to represent the complex relationships between land characteristics and land uses to predict the land suitability for a land unit. The first three approaches are good examples of qualitative approach to land evaluation whereas the process modelling approach quantifies land qualities numerically. Hence, it is classified as probabilistic, dynamic and quantitative method of land evaluation which means it can include fuzzy datasets as inputs, can take dynamic information and use quantitative calculations for land evaluation. However, the method's practical superiority has not yet been established in land evaluation programs in Australia (McKenzie 1991:12).

van de Graaf (1988) categorized land evaluation methods based on their mode of operation. His first two categories allocated a land unit into pre-determined land use classes based on the limiting factors present in that land unit, and were described as "segmented systems". According to FAO frameworks (1976, 1980, 1983 and 1985), land capability classification applies to general agriculture and suitability classification specifically refers to certain land use types and a land unit's potential to support them. FAO's frameworks also gave much impetus to economic and social factors along with biophysical factors associated with a land unit for assessing its suitability for a land use. These segmented systems essentially attempt to provide qualitative classifications of land units classifying them among as suitable, marginal or unsuitable for a particular land use. The third category proposed by van de Graaf (1988) is a quantitative approach which includes arithmetic land evaluation systems. Arithmetic systems provide a continuous numeric scale of assessment for land units and these systems are also referred as "integrated systems", as they consider several factors to quantify agriculture potential of land.

Ableiter (1937) and Huddleston (1984) classified quantitative (integrated) land evaluation systems as either inductive or deductive systems. Inductive systems use a mathematical expression to imply the overall potential of a land unit combining several factors, while deductive systems use crop yield measurements to classify and rank land units. Inductive systems are further classified into three subcategories namely, additive, multiplicative and complex systems based on the type of mathematical operation employed. Figure 5.1 presents an overview of approaches adopted in land evaluation so far, and also shows the approach adopted by the current research.

Figure 5.1 Different approaches to land evaluation including that taken by the current research (Adapted from Shields, Smith & McDonald (1996:13) including that taken by the current research



5.3 Knowledge based approach to land evaluation

The method adopted in the current research is a mixed, all-in-one, type approach which uses the positives of the methods mentioned above. The knowledge-based approach involves the collection and use of knowledge rules that govern land evaluation process. The type of knowledge rules can be drawn from trial and error methods, empirical studies and process modelling methods. A variety of qualitative, quantitative and heuristic factors can be translated into knowledge rules that can be used in the process of land evaluation. As shown in the Figure 5.1, the current approach to land evaluation starts with the results of physical land capability classification done at a regional scale. A qualitative assessment of physical factors is sufficient to classify land units on a regional scale. When the land evaluation is done at the farm level, the physically evaluated land use options are explored from economic, social and political perspectives to prescribe suitable crop choices for each farm unit. At this stage, quantitative, qualitative and heuristic knowledge rules can be brought in so that each farm unit is assessed on these knowledge rules and an appropriate land use or crop is allocated accordingly.

5.4 Crop suitability analysis

The problem of crop selection is a historic problem. Some lands possess abundant resources which can support a diversity of crops. Other lands restrict crop choices. The term "land capability" defines a land unit's ability to support particular land uses, such as agriculture or forestry and while "land suitability" refers to the land unit's ability to support a particular crop such as wheat, canola or grape (McRae & Burnham 1981:3). Day and Howe (1986) and David Masscmedt (1993) (both quoted in Shields, Smith & McDonald 1996:11) argue that physical land characteristics are sufficient to predict the land capability but to assess the land suitability for a specific crop, other factors such as economic, social and political factors are needed. There are number of factors or parameters which affect crop choices, which can vary widely across different geographical regions. The common ones are listed in the Table 5.1 with their relative influence on the evaluation processes at regional and farm level.

Table 5.1 Factors involved in agricultural land evaluation and crop suitability analysis

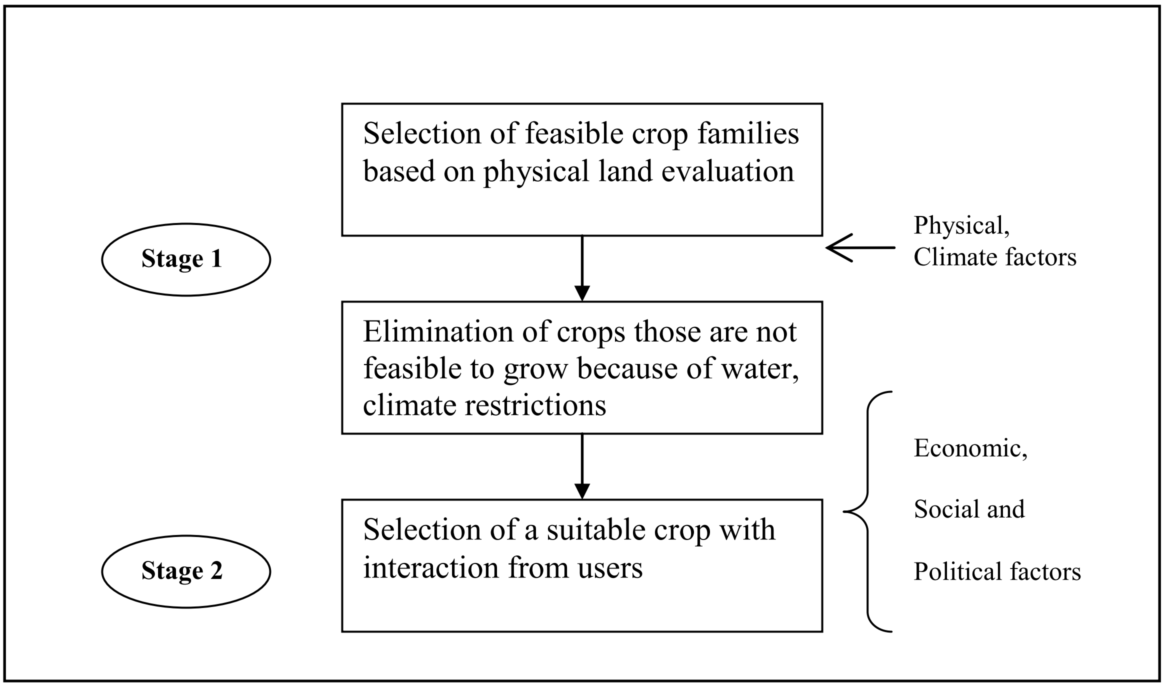
Physical Factors	**Does the factor has an influence at**	
	Regional level?	**Farm level?**
Topography	Yes	Yes
Irrigation availability	No	Yes
Soil fertility and physical conditions	Yes	Yes
Waterlogging / salinity / drainage	Yes	Yes
Soil depth / water storage	Yes	Yes
Chemical barriers to root growth	Yes	Yes
Erosion potential	Yes	Yes
Water quality	Yes	Yes
Climate and rainfall	Yes	Yes
Economic Factors		
Size and nature of land	No	Yes
Profitability (Costs/Returns)	No	Yes
Market Price and Demand for a crop	No	Yes
Access to Market	No	Yes
Other factors		
Crop Rotation	No	Yes
Equipment & Labour	No	Yes
Government policies and restrictions	Yes	Yes
Environmental factors	Yes	Yes

Certain physical factors such as topography and climate play a major role in land classification at the regional level, and they decide the major land use for a region. Other factors such as market price, market demand for a crop, availability of labour and machinery play a vital role in deciding a suitable crop for a farm unit. Hence, a two-stage knowledge-based evaluation approach (see section 5.5) is adopted in the current research to help farmers in selecting a suitable crop for their land unit.

5.5 Procedure for crop suitability analysis

Crop advisors perceive the land evaluation process as a problem-solving activity. They use their past experience and lessons from past mistakes to suggest crops based on the available resource conditions. Crop advisors make use of regional soil surveys, land classification results and suitability maps released by Government agencies (see section 2.5 for more details). Crop advisors not only base decisions on the current situation, but also consider future trends on market factors and government policies to suggest a particular crop for a land unit (Ruud, Huirne & Anderson 2004:234). The current knowledge-based "Crop Advisor" system is being developed with the help of the Department of Water, Land and Bio-diversity Conservation (DWLBC), South Australia. The expert system outlined in the current research imitates the problem-solving approach adopted by a crop advisor and it is designed based on the knowledge provided by officials at DWLBC. The "Crop Advisor" expert system adopts a combined land evaluation and crop suitability analysis methodology consisting of two stages of decision-making (Figure 5.2). The initial stage involves identification of a suitable set of crops considering physical spatial attributes, and the elimination of crop choices that are not feasible due to soil and physiographic resources. The second stage involves the user's interaction to identify few suitable crops based on various social, economical and political inputs from the user. The methodology uses regional spatial datasets in the initial stages, and as it proceeds to farm level, it uses the inputs from farmers.

Figure 5.2 Stages involved in land evaluation and crop suitability



The assessment criteria (see Appendices I, & II for more details) used in the physical evaluation has been adapted from the DWLBC Guidelines and Methodology for Assessing Crop Potential (DWLBC 2003a) and other factors used in economic, socio-political evaluation are gathered from the agricultural experts at DWLBC and from various departments of South Australian Government. For this research, a crop expert and land evaluator Mr. David Maschmedt agreed to act as the human expert who provided the knowledge for the development of the prototype 'Crop Advisor'. The knowledge rules collected by the researcher were individually verified and checked by Mr. David Maschmedt before they were coded into the 'Crop Advisor' system. Whilst the system can be scaled to include multiple experts from different disciplines, this is beyond the scope of this thesis.

5.6 Summary

The chapter discussed the different type of approaches adopted in land evaluation studies and discussed the knowledge-based approach adopted in the current research. The chapter listed the factors used in the land evaluation and crop suitability analysis and their relative importance to the overall decision-making process. It briefly outlined a two stage plan for agricultural land evaluation and crop suitability analysis which will be discussed at length in the next chapter.

CHAPTER 6
METHODOLOGY

6.1 Introduction

The methodology adopted in this research for developing the "Crop Advisor" expert system, a knowledge-based, spatial decision support system, is briefly outlined in the present chapter. The land evaluation process starts from a broad assessment of land resources at a regional scale and proceeds to the selection of optimal crops that can be grown in a farm unit. As the land evaluation process is a multi-disciplinary problem, it requires different kinds of knowledge at various scales. The regional level land evaluation is primarily based on soil and physiographic data, climate, water availability data and gives a likely indication of feasible crops that can be grown in a region. It is a rigorous process of elimination of options (crops) that are not suited for that region. The farm level decision making (refer to Chapter 2 section 2.5 and 2.6) requires the land owner's participation and it is an interactive process in which farmers can choose or omit certain factors that are to be used in the assessment to evaluate crops for their farm units. Such factors include economic data (market information), climate (average rainfall in the farm unit), soil physiography, water availability (for irrigated crops), social considerations and government regulations.

The emphasis of the current research is that a knowledge-based land evaluation model could accommodate qualitative, quantitative, heuristic assessment factors more efficiently than other approaches (refer to sections 5.2 and 5.3 for details) of land evaluation. To prove that this knowledge-based approach works, a proof-of-concept prototype model has been developed. The types of factors used in the land evaluation process are chosen in such a way that some factors are qualitative, and classified on a relative scale (low, medium and high), while other are quantitative, and are numerically quantified (amount of rainfall, market price). Others are of heuristic type, which is based on human judgements such as the extent of government support for a crop.

6.2 Physical land evaluation by DWLBC

The purpose of developing this knowledge-based "Crop Advisor" expert system is to help farmers in choosing an optimal crop that can be grown on their land. Currently, the Department of Water, Land and Biodiversity Conservation (DWLBC) of South Australia uses soil and physiographic data to generate crop-wise suitability maps for a region on a mapping scale of

1:100,000. These maps were derived by interpreting 1:40,000 scale aerial photographs for most parts of South Australia. These maps play an important role in strategic land use planning at regional scale and in making regional level land use decisions. Such regional plans help farmers to develop their farm-level land use plans. The Department of Water, Land and Biodiversity Conservation of South Australia has developed an assessment methodology (DWLBC 2003a) for physical land evaluation which evaluates soil and landscape parameters of a region to assess its suitability for different crops. This methodology uses soil and landscape mapping data bases compiled for the agricultural districts of South Australia between 1990 and 2000 (DWLBC 2003b). Each mapped soil landscape unit has been classified with respect to a range of attributes which affect agricultural land use and thereby crop suitability. These attributes include susceptibility to waterlogging, acidity, salinity, rockiness and another 31 attributes (see Appendix I for the list of attributes). Each crop has a specific requirement of these attributes and a criteria table is developed to define these crop requirements in terms of these attributes (refer to Appendix IV for the criteria developed for assessing canola crop). By matching the values of these land attributes with the requirements of specific crops, the relative potential of a particular soil landscape unit to sustain a particular crop can be predicted.

Based on these methods, DWLBC has developed an Arc Macro Language (AML) program that can be executed in the ArcINFO (ESRI 2005) environment to evaluate soil and landscape data and subsequently produce a suitability map for a certain crop for any region. Each farm unit is evaluated based on a number of physical factors such as topography, waterlogging, salinity, drainage conditions, soil depth, water storage, chemical barriers to root growth, soil fertility, and erosion potential (refer to Appendix II for more details) to classify the land for its suitability to grow a particular crop. The land is classified into one of the five classes of suitability, from High suitability to Low suitability, as shown in Table 6.1. For example, it produces a “potential lands suitable for olives” map (see Figure 6.1), showing land units under five categories (from highly suitable to not suitable). The program needs to be executed for every crop to identify whether a land unit is suitable for that crop. The difficulty with this approach is that a farmer needs to look at a number of individual crop suitability maps (DWLBC 2003c) (Figures 6.1 and 6.2) to find the most suited crop. In other words, a farmer may need to execute the program up to 37 different times to find the best crop suitable for a land unit. A full list of crops grown in South Australian agriculture districts is presented in Appendix III.

Table 6.1 Five land suitability classes and their general definitions (DWLBC, 2003a)

Class	Suitability	General definition
Class 1	High suitability	Land with high productive potential and requiring no more than standard management practices to sustain productivity.
Class 2	Moderate to high suitability	Land with moderately high productive potential and / or requiring specific, but widely accepted and used, management practices to sustain productivity.
Class 3	Moderate suitability	Land with moderate productive potential and / or requiring specialized management practices to sustain productivity.
Class 4	Marginal suitability	Land with marginal productive potential and / or requiring very highly specialized management skills to sustain productivity.
Class 5	Low suitability	Land with low productive potential and /or permanent limitations which effectively preclude its use.

Figure 6.1 Suitable land units for growing Olives (suitability classes relate to those in Table 6.1)

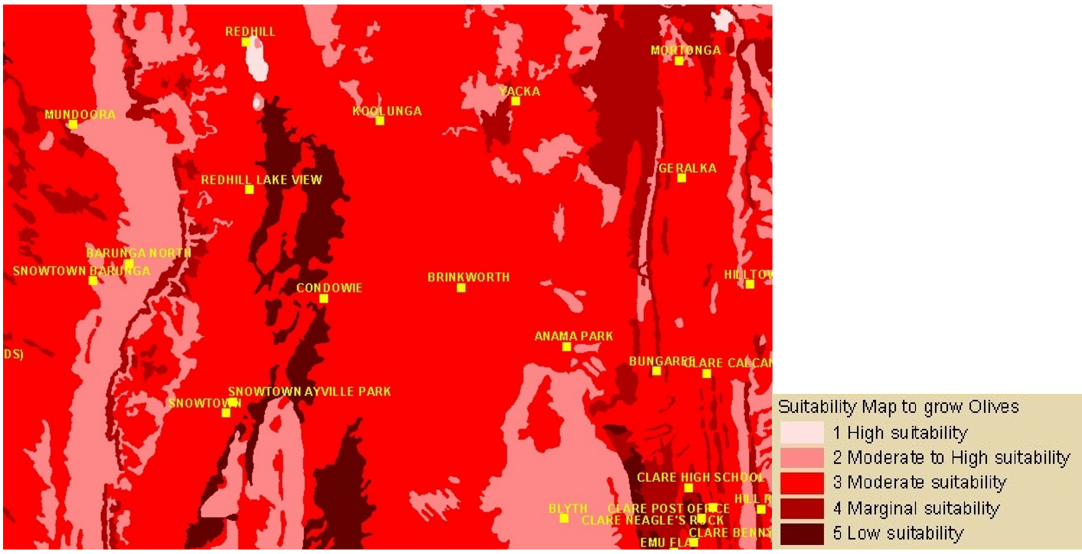
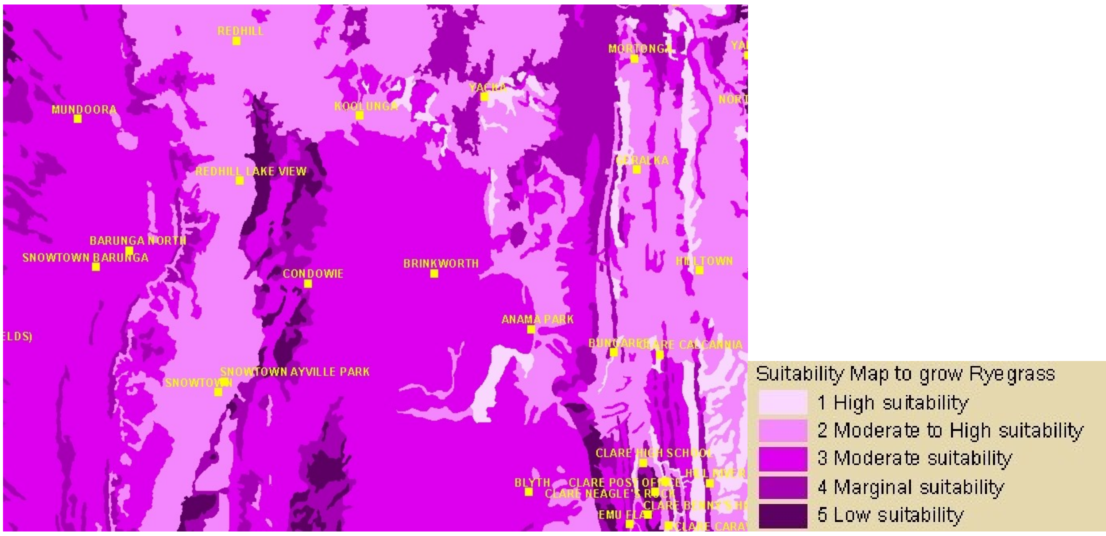


Figure 6.2 Suitable land units for growing Ryegrass (suitability classes relate to those in Table 6.1)



The main purpose of the land suitability assessment program developed by DWLBC is that they would be useful in regional land use planning and strategic decision-making. The mapping scale is 1:1, 000,000, which means they will be of little use to farm-level decision making processes, but since there is no other spatial data available at a mapping scale closer to farm level, the 1:100,000 scale data is used in the current research. The present knowledge-based system builds on the existing program to extend its capability to suggest suitable crops that can be grown in a farm unit. The scale of farm maps that are going to be used is 1:10,000 which shows demarcated boundaries and survey numbers associated with each farm unit. Using the land suitability maps developed by DWLBC, the crop families that are not suitable for a farm unit can be eliminated at the initial level. This elimination is based on the physical land evaluation done by DWLBC considering only soil and physiographic factors. Hence, the present “Crop Advisor” knowledge-based system considers additional factors for land evaluation and crop suitability and uses a non-spatial method, but spatial datasets can be included in the future.

6.3 Suitability analysis

This research extends the DWLBC approach to take the land evaluation and assessment for determining crop suitability to the farm level. This research builds from the existing DWLBC methodology, but uses additional factors such as climate, water supply, labour and machinery availability, market factors and political factors to assess a land unit and then suggest the best suitable crop. It also overcomes some of the limitations of the land evaluation program developed by DWLBC. The current thesis assumes that a farmer is interested in knowing the best crop that can be grown in a farm unit and doesn't want to go through the individual evaluation processes for each crop. The 'best crop' here refers to the one that is most profitable by economic standards and the one that fit within the strategic land use plan developed at a regional scale. This can be fulfilled by evaluating a farm unit for its suitability for all the crops and then ranking the crops suited to the farm unit in a descending order of suitability. The program evaluates a land unit for all possible crop options at a single attempt. The program assumes all 37 crops can be grown in a land unit and progressively eliminates, based on resource availability, the crops that are not feasible to be grown on that unit. Essentially, the program needs to eliminate the non-feasible crops and list, the most suited ones for each farm unit. The first step in the process is to combine the individual crop assessments made by DWLBC into a GIS to extract a farm-based crop suitability database. The next step involves ranking the crop choices in order of suitability. The resulting database will have, for each farm unit, the crops suited to that map unit allocated in a descending order of suitability; the most suitable crop at the top to the least suitable crop at bottom, as shown in Table 6.2.

Table 6.2 Database showing suitability order of crops for a farm unit

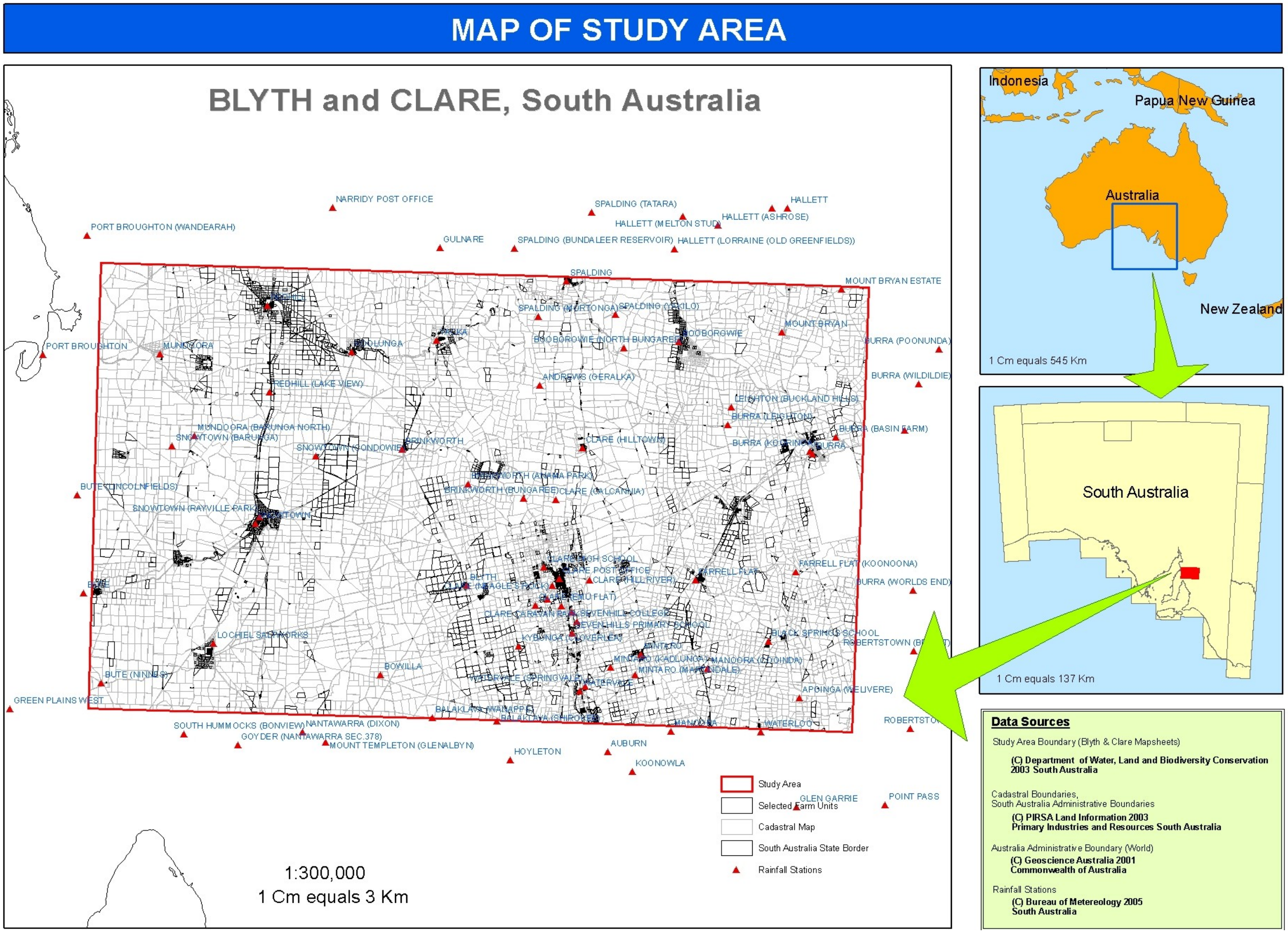
Survey Number	**H210800 S605**
Crop Choice 1 (Most suitable)	Canola
Crop Choice 2	Chickpeas
Crop Choice 3	Faba beans
Crop Choice 4	Field peas
Crop Choice 5	Grapes
Crop Choice 6	Grasses
Crop Choice 7	Legumes
Crop Choice 8 (Least suitable)	Lucerene

Later, with inputs from land owners, the "Crop Advisor" expert system should narrow down to the most suitable (optimal) crop that can be grown in a land unit. The inputs from land owners include the water supply (either rainfed or irrigated), labour supply (low, medium or high), machinery availability (yes or no) for the farm unit which is under consideration. The land owner has an option of including assessment factors such as government regulations and market factors (price and demand) in the assessment process.

6.4 Study area

The study area adopted for the current research is Blyth and Clare districts, which fall within the Central districts of South Australia, shown in the Figure 6.3. It is covered by map sheets 6530 and 6630 of scale 1:100,000 on PIRSA spatial database (PIRSA 2003). The geographical region of Blyth and Clare has a varying topography of hills and valleys with elevation ranging from 300 to 500 metres. The rainfall months are predominantly June to September during winter and spring seasons with generally dry summer months. The soils vary from red to brown grey and support major crops such as wheat, maize, canola, oilseeds and grapes. A total of 9000 farm units were arbitrarily selected from the study area and the crop choices from DWLBC physical land evaluation were joined based on their spatial location. For each farm unit, a group of crop choices (maximum of 20) are assigned on the descending order of their suitability with most suitable crop as choice 1 and least suitable crop as choice 20.

Figure 6.3 Map showing the study area of Blyth and Clare



6.5 Summary

This chapter discussed the methodology adopted in the current research and how it has been constructed from the existing DWLBC method of land evaluation and crop suitability. The current research method significantly varies from the DWLBC approach as the emphasis is placed on the farm units rather than a region. The importance of a knowledge-based approach is also brought out in this chapter as the current research follows a non-spatial approach at farm level to find suitable crops for a farm unit. The study area chosen for the current research is briefly described. The next chapter will outline the design and specifications of the “Crop Advisor” expert system and will discuss the factors included in the knowledge-base and their relative importance for land evaluation and crop suitability analysis.

CHAPTER 7
DESIGN AND SPECIFICATIONS

7.1 Introduction

The purpose of the current knowledge-based system is to suggest an optimal agricultural crop best suited for a land unit based on its potential. The land can be evaluated for its suitability to grow a particular crop based on a number of parameters. These parameters have been listed in Appendix I and their degree of influences on crop suitability were analyzed in Chapter 4. Chapter 4 also briefly explained the user needs and expectations of farmers. In the current chapter, the design and specifications of the "Crop Advisor" expert system is outlined, covering the system specifications, data used and target users. The chapter further explores how the knowledge base is designed and the software tools and application environment used in the development process of the expert system. The final section of the chapter details the system architecture on which the expert system is built and how the software tools fit into the architecture.

7.2 Targeted users and data sources

The primary user groups of the current "Crop Advisor" expert system are farmers, agricultural advisers and land use planners. Other users of the system could include administrators, scientists and students.

The knowledge base forms a key component of the "Crop Advisor" expert system and lists different agricultural crops and their resource requirements and thereby defines the criteria for choosing a suitable crop. The criteria have been developed for each crop by agricultural scientists at DWLBC. As a part of this current research, additional factors such as social, economic and political factors needed for crop suitability analysis were determined by consulting experts at DWLBC (see section 7.3) and listed in the form of a criterion table. Various spatial databases such as digital cadastral maps, soil and landscape maps, rainfall data and physical crop suitability maps were used in preparing the farm database. The datasets originate from different ground surveys and remote sensing (satellite observation and aerial photography) methods. For example, the rainfall data is collected by daily measurements at ground stations and the soil database is prepared by interpreting remotely sensed images with limited field-level ground observations. The spatial databases were converted to a database format that is readily usable by the "Crop Advisor" expert system. A spatial layer of rainfall was generated using the geographical locations of rainfall stations and the average annual rainfall value received by each farm unit. A farm database, which has a listing of every farm unit in the chosen study area with initial crop choices and average rainfall occurring in that farm unit, is prepared which forms the input for the crop suitability process.

The social, economic and political factors, (for more details refer to section 7.3), are generally non-spatial. Economic factors such as market price and market demand for a crop produce, labour and machinery availability factors are also represented in the expert system's knowledge bases. Market prices were collected from Profarmer online newsletters (ProFarmer Australia, 2006) and FAO statistics division web portal (FAO 2006). Market demand is crucial in determining the supply-demand economics of a particular crop. By accurately measuring the market demand or predicting seasonal demand for a crop product, its optimal selling price can be determined. If the market demand is high, the price for that crop will be high and vice-versa. The market demands for the crops were randomly assumed at present as they could not be obtained from real market places. However, seasonal demands of various crops and their variations can be estimated by studying the market over a period of time. Currently, market demand is classified into three categories viz., low, medium and high. If the demand for a particular crop is below its average market demand, then the demand is assumed low. Political factors such as government regulations or restrictions, subsidies on certain crops are essential to choose a crop and therefore are a part of the "Crop Advisor" database. The political factor can be considered as a heuristic[2] factor which depends on the human judgment of an expert who will input this information into the knowledge base. These types of information are highly dynamic and need to be periodically updated by the expert. Much of the crop knowledge base data used in the "Crop Advisor", especially the economic, and social data, have been collected from a crop expert through interviews (Maschmedt, D 2006, pers. comm., May 2006). The data and their sources are presented in Table 7.1.

[2] A heuristic factor is an objective measurement made by an expert who is specialized in a subject and it is usually based on empirical observations.

Table 7.1 Datasets used in the research and their sources

Data	Specifications	Year of Publication	Agency / Custodian
Crop suitability maps based on soil and physiographic evaluation	Blyth and Clare region; Map sheets	2003	Department of Water, Land and Biodiversity Conservation, South Australia (DWLBC)
Land use land cover map	Blyth and Clare region; Map sheets	2003	DWLBC
Digital Cadastral Database	Farm units with survey number	2003	Department for Environment and Heritage, Government of South Australia
Meteorological Stations	South Australian rainfall station locations	2005	Bureau of Meteorology, South Australia
Temperature and Rainfall	Rainfall stations (Point data) covering the study area	2005	SILO, Bureau of Meteorology, http://www.bom.gov.au/silo
Water availability	Surface, Groundwater, Pipelines	2003	PIRSA Land Information Primary Industries and Resources South Australia
Market information	Market prices in A$ per Tonne	2005-06	FAO, Profarmer Newsletters
Crop knowledge base	Collected by interviewing expert	2006	DWLBC (See Table 7.2)
Administrative boundaries – Australia, South Australia		2001, 2003	PIRSA Land Information Primary Industries and Resources South Australia, Geoscience Australia

7.3 Knowledge engineering for "Crop Advisor" expert system

Through years of experience in conducting soil surveys and land evaluation in South Australia, land use experts at DWLBC have developed a body of knowledge that can be used in land evaluation and crop suitability analysis. The knowledge that is used in the current research has been assembled by interviewing experts, using published reports and from the Internet. Primarily, the knowledge base for the "Crop Advisor" contains the conditional requirements of each crop choice, and how a factor decides crop suitability for a farm unit. The conditional requirements relate to crop water requirements – average rainfall or irrigated water, labour inputs -low, medium or high, machinery requirement for cultivating a crop -required or not required, market factors -market price, demand for a crop and government support for a crop -favourable or not favourable. The values for each factor are just representative only as in some cases, a factor can have more than two or three categories. For example, the Machinery requirement could be classified into Low, Medium and High requirements instead of 'required' or 'not-required' classes. As this research involved the development of a prototype model, simple classes were used. These knowledge rules are defined in Table 7.2. The advantage of a table format is that it is very easy to verify, modify and update the knowledge base.

Table 7.2 Table showing the knowledge base of crop requirements

Crop	Price A$/Tonne	Rainfall	Labour	Machinery	Govt. Regulations	Market Index	Normalized Market Price	Demand
Almond	5,550	300-700	Medium	No	Favourable	24.58	74.50	Medium
Apple	1,170	370-590	Medium	No	Unfavourable	7.85	15.70	High
Barley	255	350-500	Low	Yes	Favourable	1.13	3.42	Medium
Brassicas	890	400-700	Medium	No	Favourable	5.97	11.95	High
Canola	510	350-700	Low	Yes	Favourable	3.42	6.85	High
Carrot	350	450-650	Medium	No	Unfavourable	1.55	4.70	Medium
Cherry	7,450	400-600	High	No	Favourable	50.00	100.00	High
Chickpea	500	400-700	Low	Yes	Favourable	3.36	6.71	High
Citrus	747	200-400	Medium	No	Favourable	1.70	10.03	Low
Field Pea	200	400-700	Low	Yes	Favourable	0.89	2.68	Medium
Faba Beans	230	320-560	Medium	No	Favourable	0.52	3.09	Low
Grapevine	862	250-400	High	No	Favourable	5.79	11.57	High
Grapevine Medium	530	250-300	Low	No	Favourable	2.35	7.11	Medium
Grasses	670	200-300	Medium	Yes	Favourable	2.97	8.99	Medium
Grazing	540	150-350	Low	No	Favourable	3.62	7.25	High
Lavender	500	300-550	Medium	Yes	Favourable	2.21	6.71	Medium
Lentil	510	300-500	Low	No	Favourable	3.42	6.85	High
Legumes	400	350-550	Medium	No	Unfavourable	1.77	5.37	Medium
Lucerne Dryland	530	300-500	Low	Yes	Favourable	3.56	7.11	High
Lucerne Irrigated	570	240-490	Low	Yes	Favourable	3.83	7.65	High
Lupin	291	500-650	Low	Yes	Favourable	0.66	3.91	Low
Maize	233	400-700	Low	Yes	Favourable	1.56	3.13	High
Oats	219	350-600	Low	Yes	Favourable	0.97	2.94	Medium
Olive	2,180	300-500	Low	Yes	Favourable	4.97	29.26	Low
Onion	552	250-390	Low	Yes	Unfavourable	3.70	7.41	High
Summer Fodder	430	250-360	Low	Yes	Favourable	2.89	5.77	High
Pear	590	300-600	Medium	No	Favourable	3.96	7.92	High
Phalaris Dryland	450	300-550	Low	Yes	Favourable	1.99	6.04	Medium
Potato	222	350-500	Low	Yes	Favourable	1.49	2.98	High
Pyrethrum	450	250-500	Low	Yes	Unfavourable	3.02	6.04	High
Perennial Rye Grass Dryland	320	200-340	Low	Yes	Unfavourable	2.15	4.30	High
Perennial Rye Grass Irrigated	440	350-500	Low	Yes	Favourable	1.95	5.91	Medium
Strawberry Clover	430	350-460	Low	Yes	Favourable	1.90	5.77	Medium
Subterranean Clover	450	300-400	Low	Yes	Favourable	1.03	6.04	Low
Triticale	258	440-550	Low	Yes	Favourable	0.59	3.46	Low
Wheat	266	350-600	Low	Yes	Favourable	1.18	3.57	Medium
White Clover Irrigated	560	650-700	Low	Yes	Unfavourable	3.76	7.52	High

It is important to recognize that the knowledge base comprises only a range of basic factors. The scope and variety of factors has been constrained by time and financial factors, but are nevertheless appropriate. The methods used to derive these factors are presented in the next section.

7.3.1 Deriving the factors

To derive water requirement, the crops are classified based on their water requirements as rainfed or irrigated crops. In the case of rainfed crops, every crop has a minimum and maximum value of average rainfall (in millimeters) that is required for optimum yield. Depending on the annual average rainfall a farm unit receives, crops that are not feasible with the farm unit's rainfall are eliminated from crop choices (see section 8.3 page 96 for an example). The current market price of a crop and its market demand generate a market index, which is a quantified measure of market value of a crop. The market prices of crops vary from 222 AUD per tonne to 7,450 AUD per tonne, and hence a relative market price is used by taking the highest paying crop as reference, and then normalizing every crop's price based on it. The highest market price used in the model is 7,450 AUD per tonne for cherries. The market demand for a particular crop directly affects the market price of that crop (see section 7.2).

Normalized price of a crop = [Actual price of the crop / Highest paying crop] X 100

Normalized price of Apples = [1,170 / 7450] X 100

= 15.70

To calculate market index, normalized price is multiplied with market demand, i.e.

Market Index = Normalized Market price x Market Demand

Whereas,
Normalized market price is relative price of a crop on a scale of 1 to 100 after assuming most profitable crop's (Cherry crop has a value of 7,450 AUD per tonne) price as value 100.

Market Demand is classified into one of the three categories, Low (0.17), Medium (0.33) or High (0.5) and a proportionate numerical value is assigned to each category. To provide higher advantage to the crops that are in high demand (hence, more profitable), a market demand factor is introduced. Market Demand factor is obtained by proportionately representing the three categories of market demand that is equivalent to a total value of 100. When, the value of 100 is proportionately divided into three classes, 50%, 33% and 17% represent for High, Medium and Low market demand categories. When they are converted to an equivalent of 1, they represent 0.5, 0.33 and 0.17 as shown below.

Class	**Weightage**	**Value**
Low	17%	0.17
Medium	33%	0.33
High	50%	0.50
Total	100%	1.00

The highest value of market index can be 50 (if a normalized market price of 100 and 0.5 for "High" market demand are considered), and hence the Market Index can vary from 1 to 50. For example, Apples relative price compared to Cherries is 15.70 and its demand in market is classified as "High", and hence Market Index for apples is obtained by multiplying 15.70 and 0.5 that gives 7.85 (on a scale of 1 to 50)

The labour requirements for a crop are represented qualitatively as low, medium and high. Here, an element of expert judgment is taken into account for setting the limits of these classes in the knowledge base. Another factor which heavily depends on human judgment is the level of government support for a crop. It is classified as either favoured or unfavoured. This factor is related to the role of government in providing assistance to farmers, such as tax incentives, tax breaks, domestic and international price support policies and regulations, and other relevant restrictions determined by the government. By selecting 'unfavourable' for government support, the user can determine which crops (out of the suitable crop choices) are not favoured by government policies at the moment.

7.4 System properties

The following set of properties is the desired requirements of the “Crop Advisor” expert system. The objective has been to develop a set of properties for the “Crop Advisor” expert system so that it can be:

1. *Comprehensive*. The expert system should evaluate a farm unit for its ability to grow all of the 37 selected crops (refer to Appendix III), eliminate non-feasible crop choices and to suggest a list of optimal crops suited for that farm unit. This comprehensive approach is necessary in order to simplify the crop selection process, analyze the problem from a farmer’s perspective and consider individual farms as decision-making units.

2. *Up-to-date*. As the process of land evaluation demands knowledge from various sources, the knowledge-bases need to be kept up-to-date. It calls for a database structure which can be easily editable and which would allow network-based updating possibility. This capability would enable future development where the databases can reside at different places and the expert system can access them through network connections.

3. *Interactive*. The crucial part of the expert system lies in providing easy interaction for the end-users (farmers and land owners) with a Graphical User Interface (GUI). The Graphical User Interface has been designed to be aesthetically simple, clutter-free and easy-to-use. Help and tips for operation of every aspect of the expert system have been embedded within the user interface.

7.5 Development environment and software tools

The “Crop Advisor” expert system is developed using Microsoft Visual Basic 6.0 (Microsoft 2005), Microsoft Access 2002 (Microsoft 2002) and ArcGIS 9.1 (ESRI 2005) software. Visual Basic 6.0 is part of Microsoft Visual Studio (Microsoft 2005) which is an integrated development environment to enable programmers to create programs and software applications that run on computers with Microsoft Windows Operating Systems. Pre-built GUI tools can be simply added to develop an application without writing numerous lines of programming code to describe the appearance and location of interface elements. The "Basic" part of Visual Basic refers to the BASIC (Beginners All-Purpose Symbolic Instruction Code) language, a language used by more programmers than any other language. Visual Basic has evolved from the original BASIC language and now contains several hundred statements, functions, and keywords, many of which relate directly to the Windows GUI applications. The finished software application can be converted to an executable (.exe) file and freely distributed to anyone who can run the program on a Windows based Personal Computer. The system requirements to run the “Crop Advisor” expert system are mentioned in section 8.2 and a standard Windows Personal Computer with no specialized software is sufficient for executing the expert system. Microsoft Access 2002 is the database management tool used in building the “Crop Advisor” expert system.

MS Access 2002 is a relational database management system which combines the relational Microsoft Jet Database Engine with a graphical user interface. Microsoft defines a typical access database as a “collection of data and objects, such as tables, queries, or forms, related to a particular topic or purpose” (Microsoft 2002: Help Manual). A database in MS Access can have a number of tables in which data are stored in rows and columns. With a programming language such as Visual Basic (VB), software applications can be developed with MS Access for managing databases. MS Access offers Open Data Base Connectivity (ODBC), a standard database access method, which enables a programming language like Visual Basic to access data from any application, regardless of which database management system (DBMS) is handling the data. It manages this by establishing a middle layer, called a database driver, which communicates between an application and the DBMS. The purpose of the database driver is to translate queries (data requests, for example from farmers) from the application into commands that the DBMS understands. Visual Basic and MS Access are ODBC-compliant – the application developed using Visual Basic is capable of issuing ODBC commands and the DBMS in this case, MS Access, is capable of responding to the commands. There are two tables contained in the MS Access database (See Figure 7.1), viz.,

(i) Farm database which has the farm records and initial crop choices that resulted from physical land evaluation and average rainfall for that farm unit and

(ii) Crop database which has a list of crops and their individual requirements (criteria) for different factors such as labour and machinery requirements.

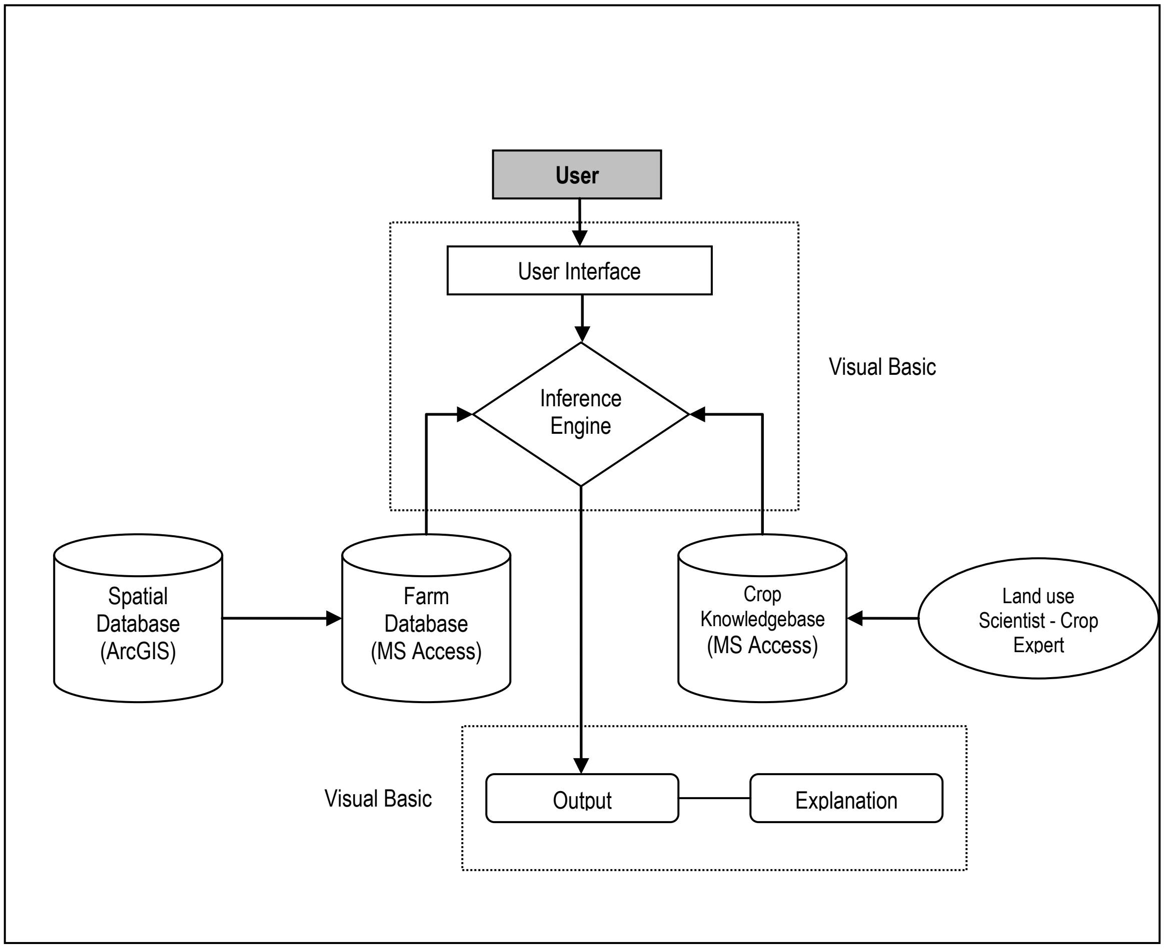
Modifying the criteria in the MS Access database involves simple modification of values in the row against a crop. If a new criterion has to be added such as “minimum area needed to grow the crop”, a new column is added into the Crop database and the values of minimum area required to grow each crop can be entered. When a farmer selects a farm unit, the area of the farm unit is read from the Farm database and compared with the crops that satisfy the minimum area, and suitable crops are short listed. Since the expert system is customized to reflect any changes in the MS Access database, from the next run, the new criterion can be included in the analysis by adding a user interface element in the Graphical User Interface. However, the provision to add a new factor into the expert system has not been developed due to time constraints, although section 9.4 discusses how this feature can be achieved.

ArcGIS 9.1 (ESRI 2005) is a group of Geographic Information System software tools developed and marketed by Environmental Systems Research Institute (ESRI). ArcGIS 9.1 is useful to view, edit, and query spatial data and their associated attribute tables. The spatial data required by the “Crop Advisor” were extracted and integrated using many of the spatial tools available in ArcGIS software. In particular, the farm database is extracted from combining cadastral maps supplied by PIRSA and land suitability maps supplied by DWLBC to export into a MS Access table of farm units with suitable crops stored against each farm survey number. The rainfall data supplied by the Bureau of Meteorology was converted into a spatial layer using the geographical co-ordinates of weather stations and a spatial average rainfall received by each farm was derived and stored in the farm database. In ArcGIS 9.1, an inverse distance weighted interpolation method with default parameters was used to generate the rainfall spatial layer.

7.6 Architecture of “Crop Advisor” expert system

The architecture of the “Crop Advisor” is schematically presented in Figure 7.1 and it shows how the development tools such as Visual Basic, MS Access and ArcGIS tools fit into the development framework. It also demonstrates how the information flows between various components of the expert system including the farmer (user), the user interface, the knowledge base and the inference engine.

Figure 7.1 Architecture of “Crop Advisor” Expert System



In this setup, the crop expert (land use scientist) provides the necessary knowledge rules to build the knowledge base. The spatial operations are performed using the GIS tools provided by ArcGIS, and are executed separately as a different process, after which the data are then exported into an MS Access database format (farm database) for the expert system’s use.

7.7 Summary

The chapter has provided an overview of the design and specifications of the proposed expert system. It outlined the target user groups for the “Crop Advisor” expert system in the South Australian context, specifications of the system and listed the datasets used and agencies that provided them. It has also discussed the three main components of a typical knowledge-based expert system and explained how the knowledge-base for “Crop Advisor” expert system was developed. Finally, the development environment, software tools used and the architecture of the expert system were defined. The next chapter discusses how the expert system functions to achieve land evaluation and presents a step-by-step approach to illustrate how a farm unit is assessed by the “Crop Advisor” to determine suitable crops for it.

CHAPTER 8
TESTING AND FEEDBACK

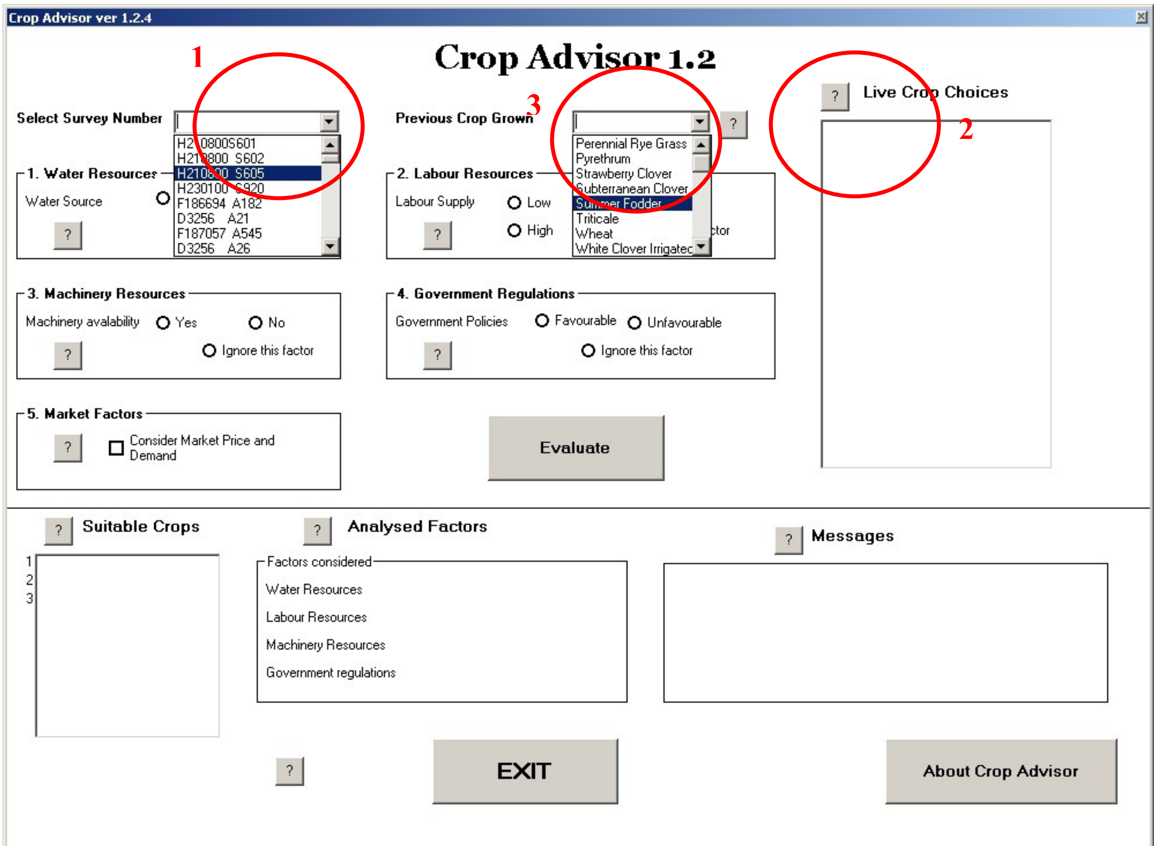
8.1 Introduction

Previous chapters have discussed the methodology involved in the process of crop suitability analysis and design and specifications of the "Crop Advisor" expert system. The current chapter describes the functioning of the expert system, various options available with the expert system with screenshots. Considering a farm unit as a case study, the working of "Crop Advisor" expert system is illustrated in a step-by-step process. It then proceeds to test the expert system by validating the recommendations given by the expert system. It lists the feedback received from its early use in a controlled software testing environment.

8.2 Functioning of "Crop Advisor" expert system

A standard Windows Personal Computer is essential to install and execute the "Crop Advisor" expert system. The system requirements for using the "Crop Advisor" expert system include a Windows operating system, 128 Megabytes of RAM (Random Access Memory), 10 Megabytes of free disk space and a monitor with at least 800 by 600 pixels resolution. Figure 8.1 shows the user interface when the "Crop Advisor" expert system is initialized.

Figure 8.1 Main screen of “Crop Advisor” expert system



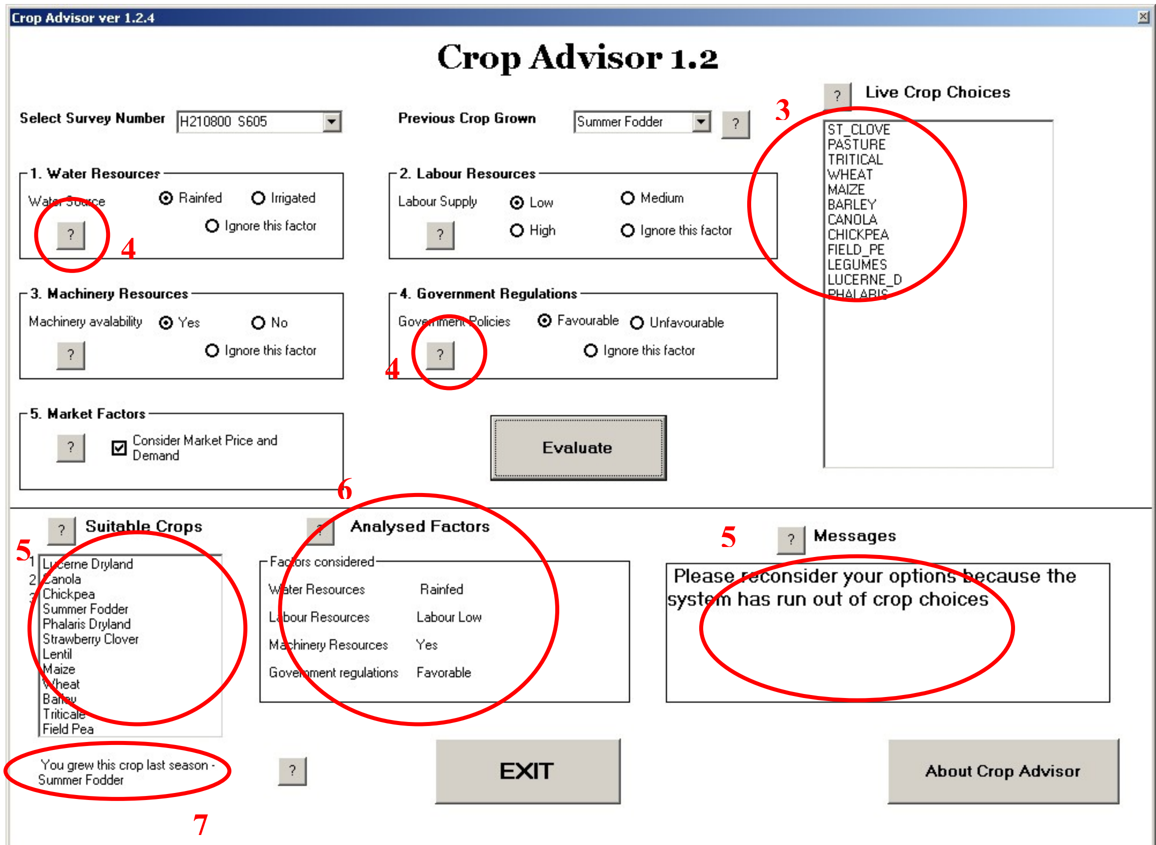
The user has the option of typing the “Survey number” (circle 1 in Figure 8.1) of the farm unit which is under evaluation or alternatively the survey number can be selected using the drop-down menu. As soon as a farm unit is selected, the live crop choices appear at the right side window (circle 2 in Figure 8.1) which is based on the physical land evaluation done by DWLBC (See section 6.2 for more details). The other input required is the previous crop (or the current crop) that is grown on the farm unit (circle 3 in Figure 8.1) to avoid cultivating same crop again. The previous year’s crop affects the productivity of a farm unit. Crop advisors suggest farmers avoid repeating the cultivation of the same crop consecutively for various reasons that include loss of soil nutrients and continuing pest life cycle. Crop rotation[3] is a process in which different crops are cultivated on a rotational basis to refurbish soil nutrients and to break the pest life cycle. However, although advice would be given to avoid the previous crop grown on the farm unit, it will appear in the final list of suitable crop

[3] Crop rotation – alternating between crops - is not widely practised in developing countries and this might be one of the reasons why farm productivity declines over time.

choices, with a note to alert the user, such as “You have already grown the crop wheat in the previous season”. Hence, the user has an option to compare their choice (previous or current grown) with the choices suggested by the “Crop Advisor” expert system. The factors for water availability, labour supply, machinery availability and government support are available for assessment by the “Crop Advisor” and their use by the farmer is purely optional. The user of the “Crop Advisor” expert system can include or exclude any combination of available factors and the resulting crop choices can be observed on the right-hand side of the user interface under Live Crop Choices[4] (circle 3 in Figure 8.2).

[4] They are called ‘Live Crop Choices’ because, the choices change dynamically as the user selects the inputs.

Figure 8.2 Executing "Crop Advisor" expert system to get suitable crops



The important point to stress is that the user actually decides which factors need to be taken into consideration by the assessment procedure and chooses options for each factor. When all the choices are made, the user can include 'Market Index' to take market price and market demand into account. When the 'Evaluate' button is pressed, final suitable crop choices appear under "Suitable Crops" (circle 5 in Figure 8.2). The three most suitable crops for the farm unit are presented in descending order of suitability.

Some combination of user inputs can result in zero crop choices. If there are insufficient crop choices available to proceed for further assessment, a reminder appears in the "Messages" box (circle 5 in Figure 8.2) which suggests that the user change the options or inputs. For example, if the user selects labour supply as "Low" and resulting crop choices are zero, then the choice for the labour supply may be changed to "Medium" or "High".

The explanation subsystem is part of the "Crop Advisor" expert system. Each factor is associated with a "?" button (for example, circle 4 in Figure 8.2) which gives further details on that factor and provides a description for the user, by clicking on the "?" button. At the end of evaluation, a message appears to remind the user of the factors that have been used in the process of crop suitability assessment (see circle 6 in Figure 8.2).

The current or previous crop grown by the farmer is highlighted underneath the crop choices with a special message – saying that the user has already grown the crop previously - (see circle 7 in Figure 8.2). This also reminds the user how the previous season's crop fares in the evaluation and crop suitability analysis. If the current crop comes in top of the table, then it is understood that the crop that is grown need not be changed unless the farmer wishes to change. It is a good way to check if the current crop choice for a farm unit is the best choice after considering the physical, economic and social factors associated with the farm unit. When the user wants to know more about the "Crop Advisor" expert system and the developers of the system, the "About Crop Advisor" button brings a "splash screen" [5] which lists the contributors who have helped in the various stages of development (see Figure 8.3).

Figure 8.3 "Crop Advisor" Splash screen

[5] A splash screen usually provides information of software, developer and people who have contributed to the development and copyright warnings.

8.3 Farm assessment: an illustrated example

To illustrate how the "Crop Advisor" expert system analyses and prescribes optimal crops for a farm unit; a case study is presented below.

The initial crop choices resulting from physical land evaluation based on physiographic and soil landscape parameters for the farm unit which has a survey number "H210800 S605" are listed in the Table 8.1. The expert system directly accesses the farm database and pulls out the survey number and its associated record showing crops suitable for that farm unit and average annual rainfall (in millimeters) received by the farm. The crop choices are represented in the form of codes to enable easy processing by the expert system and the equivalent crop names are available in the crop database.

Table 8.1 Farm table showing initial crop choices after physical land evaluation by DWLBC

DCDB_ID	H210800 S605	Crop Names
CHOICE1	BARLEY	Barley
CHOICE2	BRASSICA	Brassicas
CHOICE3	CANOLA	Canola
CHOICE4	CHICKPEA	Chickpeas
CHOICE5	FABA_BEA	Faba beans
CHOICE6	FIELD_PE	Field peas
CHOICE7	GRASSES	Grasses
CHOICE8	GRAZING	Grazing
CHOICE9	LEGUMES	Lentil
CHOICE10	LUCERNE_D	Lucerne Dryland
CHOICE11	LUCERNE_I	Lucerne Irrigated
CHOICE12	MAIZE	Maize
CHOICE13	PASTURE	Summer Fodder
CHOICE14	PHALARIS	Phalaris Dryland
CHOICE15	RYEGRASS_D	Perennial Ryegrass Dryland

CHOICE16	RYEGRASS_I	Perennial Ryegrass Irrigated
CHOICE17	ST_CLOVE	Strawberry Clover
CHOICE18	TRITICAL	Triticale
CHOICE19	WHEAT	Wheat
CHOICE20	Not available	Not available
Rain	483 (mm)	

The next step chooses the current crop grown in the farm unit. It is assumed for the case study that the farmer chooses "Strawberry Clover". Next, the farmer has to choose the water availability for the farm unit - whether the farm unit depends on rainfall or irrigated water for agriculture. If the choice is "Rainfed", the average annual rainfall of the farm unit is taken and the crops which can be sustained with that rainfall amount are short listed. If the choice is "Irrigated", then the crops which are profitable with irrigation cost and expenses are suggested. In the present example, the farmer chooses "Rainfed" for the water availability option, which causes crops which require irrigation to be eliminated and crops which can be grown with the farm unit's rainfall are listed on the "Crop Advisor" screen and theses are shown in Table 8.2.

Table 8.2 Elimination of crop choices based on rainfall

DCDB_ID	**H210800 S605**	**Status**
CHOICE1	BARLEY	Barley
CHOICE2	BRASSICA	Brassicas
CHOICE3	CANOLA	Canola
CHOICE4	CHICKPEA	Chickpeas
CHOICE5	FABA_BEA	Faba beans
CHOICE6	FIELD_PE	Field peas
CHOICE7	GRASSES	Eliminated (Needs Irrigation)
CHOICE8	GRAZING	Eliminated (Too much Rainfall)
CHOICE9	LEGUMES	Lentils
CHOICE10	LUCERNE_D	Lucerne Dryland
CHOICE11	LUCERNE_I	Eliminated (Needs Irrigation)

CHOICE12	MAIZE	Maize
CHOICE13	PASTURE	Eliminated (Too much Rainfall)
CHOICE14	PHALARIS	Phalaris Dryland
CHOICE15	RYEGRASS_D	Eliminated (Too much Rainfall)
CHOICE16	RYEGRASS_I	Eliminated (Needs Irrigation)
CHOICE17	ST_CLOVE	Strawberry Clover
CHOICE18	TRITICAL	Triticale
CHOICE19	WHEAT	Wheat

Each crop has a specific lower and upper limit of rainfall that is required to reach its optimal crop production. The average rainfall received by the farm unit should be more than the minimum rainfall (lower limit) required by the crop. The crops which require more rainfall than the average rainfall received by the farm unit are eliminated by "Crop Advisor". The farm unit's rainfall should not exceed the maximum amount of rainfall (upper limit) that can be required by a crop. Too much rainfall may diminish the crop yield and may not give optimal outputs. For example, if a farm unit receives an average of 400mm rainfall and a crop has lower and upper limits of rainfall requirements as 300 and 500mm respectively, then the farm unit will sustain the crop. In this case, the rainfall limits required by "Dryland Ryegrass" is 200 to 340 mm and the farm unit's average rainfall, 483 mm exceeds the upper limit of the crop – so, it would result in decreased crop efficiency. Hence, "Dryland Ryegrass" is dropped from the list by the "Crop Advisor" inference engine.

The next step for the user is to enter the amount of available labour for the farm unit. "Crop Advisor" provides three options – low, medium and high. In the case study, the user chooses low labour and the crops that require high and medium labour supply are eliminated from the crop choices. Those crops that remain as options are shown in Table 8.3.

Table 8.3 Crop choices after labour availability factor is evaluated

DCDB_ID	**H210800 S605**	**Status**
CHOICE1	BARLEY	Barley
CHOICE2	BRASSICA	Eliminated (Medium labour)
CHOICE3	CANOLA	Canola
CHOICE4	CHICKPEA	Chickpeas
CHOICE5	FABA_BEA	Eliminated (Medium labour)
CHOICE6	FIELD_PE	Field Peas
CHOICE9	LEGUMES	Lentils
CHOICE10	LUCERNE_D	Lucerne Dryland
CHOICE12	MAIZE	Maize
CHOICE14	PHALARIS	Phalaris Dryland
CHOICE17	ST_CLOVE	Strawberry Clover
CHOICE18	TRITICAL	Triticale
CHOICE19	WHEAT	Wheat

The other factors in the evaluation include machinery resources and government regulations. If the user provides "Yes" to machinery availability, the crops which do not require machinery would be eliminated by the "Crop Advisor". The government regulation option divides the remaining crops into two categories viz.,

(i) crops favoured by government policies and

(ii) crops that are not favoured by government policies

It is assumed for the case study that the user chooses to go with the "Favourable" option - crops that are favoured by the government. When these factors are applied to the list of crop choices selected so far by the "Crop Advisor" (see Table 8.3), the list remains unchanged because, in this case, the selected crops are all favourably influenced by government regulations.

If the user wishes to apply market factors to the results, the crop choices are sorted based on "Market Index", which is derived from current market price and market demand for a particular crop (previously defined in sections 7.3 and 7.3.1). The final, optimal crop choices in the order of suitability are then generated by the "Crop Advisor" after the user presses the "Evaluate" button. In this case study example, these crops are shown in Table 8.4. The second column of the table shows the list of optimal crops without considering market factors and the third column shows them arranged based on their current market index.

Table 8.4 Table showing final crop choices for the farm unit with survey number H210800 S605

Farm unit H210800 S605	**Without considering market factors**	**Considering current market factors**
CHOICE 1	Strawberry Clover	Lucerne Dryland
CHOICE 2	Triticale	Canola
CHOICE 3	Wheat	Chickpeas
CHOICE 4	Maize	Phalaris Dryland
CHOICE 5	Barley	Strawberry Clover
CHOICE 6	Canola	Lentils
CHOICE 7	Chickpeas	Maize
CHOICE 8	Field peas	Wheat
CHOICE 9	Lentils	Barley
CHOICE 10	Lucerne Dryland	Triticale
CHOICE 11	Phalaris Dryland	Field peas

Strawberry Clover (which is at the top of the second column in the Table 8.4) is the most suitable crop without considering the market factors (current market price and market demand) which, in this case study, is also the present crop grown in the farm unit (as provided by the farmer for the option “Previous Crop Grown”). However, Lucerne Dryland crop has good market potential according to the Crop Advisor’s assessment based on market factors. A message will appear below the list of final crop choices that the farmer has already grown Strawberry Clover. The system advises the farmer that a better crop (Lucerne Dryland) is available which will provide better economic returns compared to the present crop. The user is presented with many flexible options and any crop within the first five choices are considered to yield optimal economic returns based on the physical, economic, social and political factors considered.

8.4 Testing the “Crop Advisor” expert system

The previous section discussed how the “Crop Advisor” system functions and how a farm unit is assessed by it to determine the most suitable crops. This section discusses how the “Crop Advisor” expert system was tested, and presents feedback from experts who have used the prototype system. The success of any system is measured by the degree to which the expert system’s results matches with a human expert's recommendations, sufficiency of explanations provided by the system and the consistency with which the expert system produces results without failure (Turban 1988:582). The "Crop Advisor" expert system, although in the prototype stage, showed remarkable consistency to produce reliable crop suggestions on every run. The validation of "Crop Advisor" expert system involves two stages viz.,

(i) Checking if the "Crop Advisor" expert system is valid in terms of its functions and

(ii) Verifying the results delivered by the "Crop Advisor" expert system.

The first stage involves checking if the functions of "Crop Advisor" expert satisfy the common requirements of a typical, knowledge-based system. The common characteristics of a typical expert system are reported in the literature (Turban 1988:610), and are presented in Table 8.5. The table also shows the extent to which the "Crop Advisor" expert system satisfies each characteristic.

Table 8.5 Characteristics of "Crop Advisor" expert system (based on Turban, 1988:610)

S.No	Characteristic of a typical Expert System	"Crop Advisor" prototype Expert System
1.	Expert System should address a recognized need	Yes. Need for suitable crop advice.
2.	Expert System should be easy to use even by a novice	Yes. Very simple to use.
3.	Knowledge base is kept independent of the program.	Yes. Knowledgebase remains independent.
4.	Presence of easily modifiable knowledge base	Yes. Easy to use table format.
5.	Explanation subsystem for explaining conclusions	Yes. Reasoning for working of the system.
6.	Expert System should be able to increase the expertise of the user	Yes, the knowledge rules are kept in the form of a table. Easy to understand by anyone.
7.	Expert System should be capable of learning new knowledge	No. "Crop Advisor" Expert system cannot learn on its own. Experts have to code the knowledge.

From Table 8.5, it can be seen that six of seven common attributes of expert systems are fulfilled by the "Crop Advisor". The seventh attribute – that expert systems should be capable of learning new knowledge – is more applicable to medical and legal expert systems which encounter case-by-case inputs where past events are stored in the form of knowledge base with expert's feedbacks and corrections. Such a capability is not applicable to an agricultural expert system as it operates with a common knowledge base to evaluate every land unit. Unlike the users of medical and legal expert systems, the users of the "Crop Advisor" are not experts who can correct the expert system and hence the necessary editing has to be made by experts. Currently, the knowledge base of the "Crop Advisor" system can be updated by editing the Crop database (Table 7.2). However, adding a new factor to the "Crop Advisor" expert system can be done only by editing the Visual Basic application which would require a programmer who has a hands-on experience with Visual Basic programming. The method to add such functionality to the "Crop Advisor" expert system is explained in section 9.4 where future developments are detailed.

8.5 Validating the results of "Crop Advisor" expert system

An indirect method of validation of "Crop Advisor" results (see Table 7.2) involves a thorough check of knowledge base by the experts who provided the knowledge rules. This has been done for this research and the knowledge base has been thoroughly verified. A direct method of validation of "Crop Advisor" results involves evaluating each farm unit on a case-by-case basis and field checks of the specific farms. This is, however, a very time consuming approach and has not been attempted in the present study. However, the recommendations (crop suggestions) of the "Crop Advisor" expert system can be compared by overlaying a set of selected farm units on the current land use map which contains the crop categories grown on each farm unit. As part of the valuation exercise of farm lands, DWLBC, periodically collects details of currently grown crops. These surveys categorize farm units into broad land use types such as cereals, pastures and vineyards (DWLBC 2003b). This broad categorisation means that the individual crop choices (for example, maize, canola, grapes) provided by the expert system cannot be directly compared with the land uses of the farm units (for example, cereals, grazing, irrigated vine fruits) provided by land use maps. This validation process is attempted for a few selected farm units (1312) and the results are summarized in Table 8.5. The selection of farm units is automatically done by a spatial join operation using ArcGIS. Using ArcGIS, the land uses of these farm units as reported by DWLBC are extracted. If the expert system had suggested the crops which match with the land uses presented by the DWLBC land use data, it would be considered a reasonable choice by the expert system. The first five crop choices suggested by the "Crop Advisor" expert system are taken into account for this purpose and compared with the latest available land use data provided by DWLBC (DWLBC 2003b). To obtain the first five choices from the "Crop Advisor" expert system, a standard set of inputs, rainfed, low labour, machinery availability, favourable government support and market factors, were assumed and executed for each farm unit. Assessment involved a Visual Basic routine which used these standard inputs to evaluate farm units and aggregated the resulting five crop choices for each farm unit (identified by its Survey Number) in an MS Access table. This table was exported into ArcGIS to enable a table-join, with survey number as common identifier, with the land use data provided by DWLBC. According to the DWLBC land use data, the selected farm units fell into one of six land use categories cereals, grazing and modified pastures, vineyards, legumes, oilseeds and woodland. The farm units were grouped into six land use categories with each farm unit having the crop choices (in the form of attributes) suggested by the "Crop Advisor" expert system. Table 8.6 presents a comparison (matches and mismatches) between the "Crop Advisor" expert system's recommendations and the present land use data obtained from the field observations. In 83 percent of cases, the "Crop Advisor" expert system's recommendations matched with the present land use at the farm units. However, depending on the individual user inputs by farmers, the suitable crop for each farm unit may vary.

Table 8.6 Results of "Crop Advisor" system compared with 2003 land use map provided by DWLBC

Suggested crops by "Crop Advisor" Expert System	Land use category found in the farm units in the DWLBC land use map	Number of farm units	Comments
Barley, Maize, Canola, Pastures	Cereals	549	532 matches; 17 mismatches
Lucerene (Dryland & Irrigated), Pasture, Grazing, Brassicas, Canola, Faba beans, Field peas	Grazing and modified pastures	566	404 matches 162 mismatches
Grapes, Grapevine	Irrigated vine fruits	62	62 matches 0 mismatches
Canola, Brassicas, Faba beans, Carrots, Chick peas	Legumes	60	41 matches 19 mismatches
Pasture, Canola, Triticale, Ryegrass	Oilseeds	50	32 matches 18 mismatches
Strawberry clover, Almonds, Subterranean clover	Woodland	25	12 matches 13 mismatches
	Total number of farm units	1312	1083 matches 229 mismatches
	Percentage		83% matches 17% mismatches

The validation process was partially successful, because the "Crop Advisor" expert system actually expects direct user inputs for the resource requirements for each farm unit and the results may vary according to the farmer's inputs. Considering the study area is predominantly dryland (rainfed) based, the validation process has provided a satisfactory result.

8.6 Feedback for "Crop Advisor" expert system

A selected group of land use experts and crop advisors who were involved in the knowledge base development stages of this research were given a demonstration of the "Crop Advisor" expert system and asked for their feedback and commentary. Their feedback and comments are listed below, together with details of how these have been incorporated, where possible into the "Crop Advisor" expert system. The "Crop Advisor" expert system presented in the thesis (section 8.2) has been modified on the basis of these experts feedback and comments (refer to Appendix VI for the screenshots of previous version of "Crop Advisor").

The feedback received and the improvements incorporated, where applicable are presented below:

1. **The previous crop grown on a farm unit needs to be taken into account so it may be avoided from the suitable crops suggested.**
   The option to specify the previous or current crop was included in the "Crop Advisor", and, an alert can be issued to the user if the same crop is displayed in the final crop choices. The message alerts the user to consider other crops on the basis of crop rotation purposes.

2. **If a user chooses "High" labour supply, the crop choices should not be restricted to crops that have "High" labour requirements, but also crops that have "Medium" and "Low" labour requirements as well. This is because, if a farmer has a high amount of labour supply, it is inclusive of "Medium" and "Low" labour supply requirements as well.**
   This advice has been implemented. If "High" labour supply is selected, the "Crop Advisor" selects crops requiring "Medium" and "Low" labour supply as well.

3. **The weather forecasts information can be included so the crop suitable for the next growing season can be estimated in advance.**
   This is a valid suggestion as a farmer would expect to know what crop options are available considering future weather conditions. It is possible to include weather predictions and the crop options automatically will be updated by the "Crop Advisor" expert system based on the available rainfall in the predicted season. This feedback has not been implemented in the current version of "Crop Advisor" as the data could not be obtained within the stipulated timeframe.

4. **The factor based on government regulations needs to be refined to include greater variations instead of just two classes ("favourable", "unfavourable").**

In the present version of "Crop Advisor", this is included as a heuristic factor, judged by a human expert. Although, it is possible to include a factor (possibly a numerical score or rank) based on a quantitative assessment of government impact on agriculture, such an exercise is beyond the scope of the current thesis as it requires considerable expertise and resources. It should, however, be considered in any commercial application of "Crop Advisor" that may occur in the future.

5. **It is a good prototype to start with but the factors and data need big refinements in order to give meaningful farm level assessment.**

   The principal purpose of the research for this thesis has been to provide a proof-of-concept for knowledge-based land evaluation and crop suitability (see section 5.3). The proof-of-concept has been established, and it is agreed that "Crop Advisor" will benefit enormously if farm level resource spatial data are included in the knowledge bases.

6. **The provisions to add additional factors need to be supplied.**

   In its present form, additional factors can be added only by modifying the application using Visual Basic. A method to enable additional factors to be added to the knowledge base has been explained in section 9.4, but this has not been implemented in the current version of the "Crop Advisor" expert system. Instead, new options (for example, instead of two options for water availability, three or four options could be included) can be added or modified in the knowledge base. Additional crops can be added with corresponding crop requirements such as rainfall, labour, and market factors in the knowledge base table. The expert system will accommodate such changes from the next execution. However, adding a new factor is possible in the database, but adding it in the Graphical User Interface needs a working knowledge of Visual Basic programming.

7. **The knowledge base needs to include factors that govern physical land evaluation as well.**

   Currently, the expert system reformats the individual crop suitability data supplied by the DWLBC to derive crop choices suitable for a farm unit. It is possible to include those soil and physiographic factors (presented in Appendix III) in the assessment as knowledge rules. This exercise is not undertaken due to time constraint.

8. **The market prices and market demand may change on a daily, weekly basis so provisions should be made to include the changes without manual intervention.**

   The purpose of keeping the knowledge bases separate from the program (inference engine) is to ensure such knowledge base can reside remotely. So, it is feasible to connect to web sources (databases) to obtain dynamic information on market prices and demand as and when required by the expert system. Such functionality requires collaboration from external agencies who measure market factors of crop on a periodical basis.

9. **It will be easier if farmers could choose their farm units by pointing and selecting on a digital map.**

   The process of exporting the Visual Basic application into ArcGIS is possible, but has not yet been undertaken. Once completed, users will be able to access the "Crop Advisor" expert system on a spatial format and its results will be presented in a spatial format as well.

10. **There need to be additional explanations provided at every stage to explain the users why a factor is essential for the assessment process.**

    There are help ("?") buttons presently provided. Additional information for a wide range of factors and how they contribute to the crop evaluation process is relatively easy improvement to "Crop Advisor" in due course.

11. **A compound factor of market factors need to represent both market price and market demand for a particular crop.**

    The previous version of "Crop Advisor" considered (refer to Appendix VI), considered only market price. In the present version, the current market price and market demand are combined to form a market index with a numerical scale of 1 to 50, details of which have been presented in section 7.3. A crop choice is profitable if it has a high market index value.

12. **The user should be able to omit certain factors, and still proceed with the assessment process.**

    The user has the option to select or omit a factor from the analysis. The expert system will function and provide crop choices even if some factors are omitted by the user. The factors used in the analysis are listed at the end of evaluation and appear next to the evaluated results (final crop choices).

13. **If the expert system ran out of crop choices, it should instruct users to change their options.**

    In this case, a reminder appears in the bottom-right corner (under "Messages") of the user interface that advises the user to change the options.

The feedback received regarding the "Crop Advisor" expert system has been generally favourable. Most comments are data specific, recommending the inclusion of more factors and the use of detailed spatial data and quantification of factors used in the assessment process. Most observers believe that the user interface is simple and aesthetic and provides the user with a smooth, trouble-free user experience. As it is a prototype, the knowledge base has the potential to be updated significantly by more sophisticated data collection from an expanded range of sources. The current prototype is, however, stable enough to handle queries from users and suggest suitable crops for consideration.

8.7 Summary

This chapter has provided an overview of how the "Crop Advisor" expert system prototype functions and how it assesses a farm unit to suggest suitable crops using a simple, step-by-step process. It has detailed how the prototype's functions and results were validated. It also presented some assessment of the expert system provided by a selection of persons who have been involved in the project. The author's responses to feedback and suggestions have been discussed.

CHAPTER 9
DISCUSSIONS AND CONCLUSIONS

9.1 Introduction

The current chapter revisits the research objectives and assesses the “Crop Advisor” expert system’s functions and capabilities based on the gaps identified in the literature review. It discusses the results and evaluates the merits and demerits of the “Crop Advisor” expert system. As the “Crop Advisor” expert system was conceived with Indian farmers in mind, the issues surrounding the implementation of such a system in a developing country like India are discussed. The chapter concludes with an assessment of the contributions it has made in theoretical and practical terms to the body of knowledge and charts directions for further research.

The research commenced with a two-fold objective to:

(i) develop a model for knowledge-based agricultural land evaluation and crop suitability assessment that can use different types of scientific and heuristic knowledge from various sources and

(ii) produce a prototype expert system that can demonstrate the model as proof-of-concept.

This research adopted a knowledge-based approach to farm level agricultural planning that combines knowledge-based systems methodology with GIS tools. The present approach is different from the traditional approaches to land evaluation as this can represent different types of factors such as qualitative, quantitative and heuristic factors that are associated with land evaluation. The knowledge-based expert system model enables the easy integration of these factors thus enabling collaborative decision making process. The prototype “Crop Advisor” expert system successfully demonstrated that a software tool can be developed that uses a knowledge-based approach for choosing an optimal crop for a farm unit. The knowledge-base of the “Crop Advisor” is independent of the inference engine and any necessary data changes to enhance the expert system can be easily incorporated by changing the knowledge base table. The development of “Crop Advisor” expert system is justified by the need to offer crop advice to farmers of developing countries who have no access to human crop experts (crop advisors). Crop Advisor can be used in scenarios where there is a need to use collective expertise, from multiple sources, to suggest an optimal crop and where there is a need to accommodate dynamic information into the crop evaluation process. From the feedback received, it can be inferred that the prototype "Crop Advisor" expert system has fulfilled the objective of the research.

9.2 Demerits of "Crop Advisor" prototype

There are certain limitations that can be found in the prototype of "Crop Advisor" expert system, including:

a. Adding a new factor to the system needs an intervention by a person who has an operative knowledge of MS Access and Visual Basic. Contrary to the argument made in the literature review (Refer to section 3.8), this facility is not included because of time-constraints, but, however a later section in this chapter discusses the method to do that.

b. The knowledge rules used in the physical land evaluation prepared by DWLBC are not coded into the "Crop Advisor" expert system's knowledgebase and hence, the "Crop Advisor" expert system requires the results of preliminary land evaluation done by the DWLBC. However, the factors and options used in the physical evaluation need to be revised and hence corresponding knowledge rules need to be developed in consultation with officials at DWLBC, or subsequently by other authorities if the expert system is used in India, or other developing economies.

c. The spatial data used to derive the initial crop choices are mapped at 1:100,000. This scale data is inadequate and unsuited for a farm based assessment. Since the expert system operates independent of scale, large-scale, farm level spatial data is needed to derive appropriate farm level suggestions.

9.3 Merits of "Crop Advisor" expert system

The current prototype simplifies the procedure of agricultural land evaluation and crop suitability assessment, with the following advantages:

a. It can accommodate different type of factors and heuristic types of knowledge rules can be added readily to the knowledge base. It can be potentially expanded to link many different knowledge bases that may reside at different servers (at various geographical locations) so the expert system can access the knowledge through a network when it is required to do the analysis.

b. The expert system is very simple in operation and uses no specialized, expensive expert system shells. MS Access and Visual Basic were used to develop the "Crop Advisor" expert system.

c. The knowledge base is stored in a table format enabling the knowledge rules to be edited easily.

9.4 Improvements for "Crop Advisor" expert system

Due to time constraints, many of the originally conceived features of the "Crop Advisor" expert system were not developed. The "Crop Advisor" expert system presented in this research is an improved second version (see Appendix VI for the screenshots of older version of the "Crop Advisor" expert system). This section presents the improvements that would enhance a third version of the prototype. These improvements are:

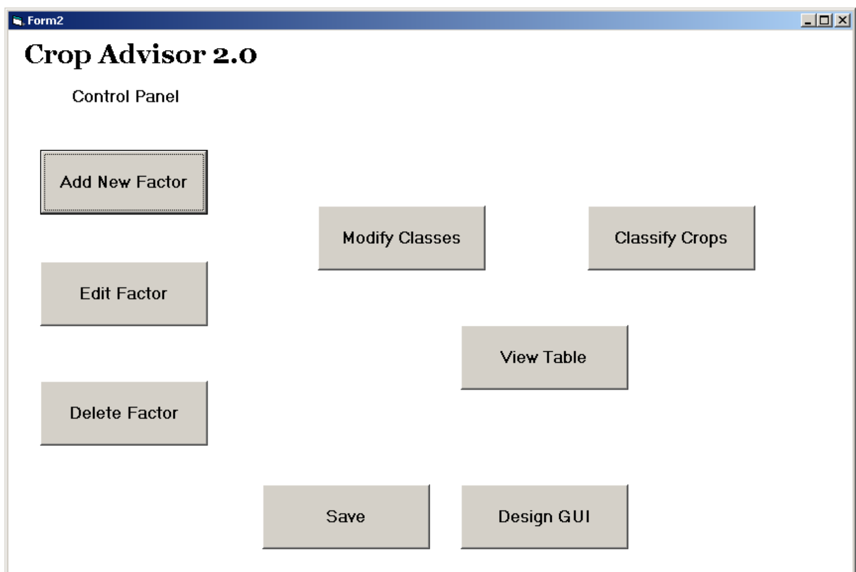
(i) **Integration of GIS:**

The analysis of spatial data to suit the "Crop Advisor" expert system involves routine streamlined GIS functions that can be integrated into the expert system with tools provided by ArcGIS manufacturers. It is possible to include the "Crop Advisor" expert system as a module into ArcGIS programme so the user can select a farm unit from a map, evaluate and get results on a spatial format that can be printed as a map.

(ii) **Adding a control panel:**

A control panel can be designed for experts who would like to add new factors, change crop options and edit the knowledge base. The control panel, as shown in Figure 9.1, will have the provision to add a new factor, modify existing factor or delete any of them. Each factor has different classes, for example, labour availability having three classes such as low, medium or high, that can be defined with "Modify classes" button. Each crop has to be classified based on every factor and by clicking the “Classify crops” button, the knowledge base table can be edited to include a new factor and add appropriate classes for each crop. The edits can be saved by clicking the “Save” button. By clicking “Design GUI” button, the graphical user interface (see Figure 8.1), the main screen of “Crop Advisor” expert system, can be re-developed to reflect the newly added factors. After this control panel is implemented, it would be possible for anyone to edit the knowledgebase without using programs such as MS Access and Visual Basic.

Figure 9.1 Control panel for “Crop Advisor” expert system



(iii) **Including dynamic information:**

It has been argued in various sections of this thesis that an expert system should be able to handle dynamic information. A number of factors can be periodically updated from internet sources. For example, the market price, market demand and weather forecasts could be accessed from web servers[6] that provide this information periodically. When the knowledge base expands with many knowledge rules, it would be necessary to use a collection of “If-Then” statements instead of having a knowledge base table. This will also allow experts include variable number of rules

[6] Web servers are a set of hardware, software tools that help to broadcast information through internet to World Wide Web.

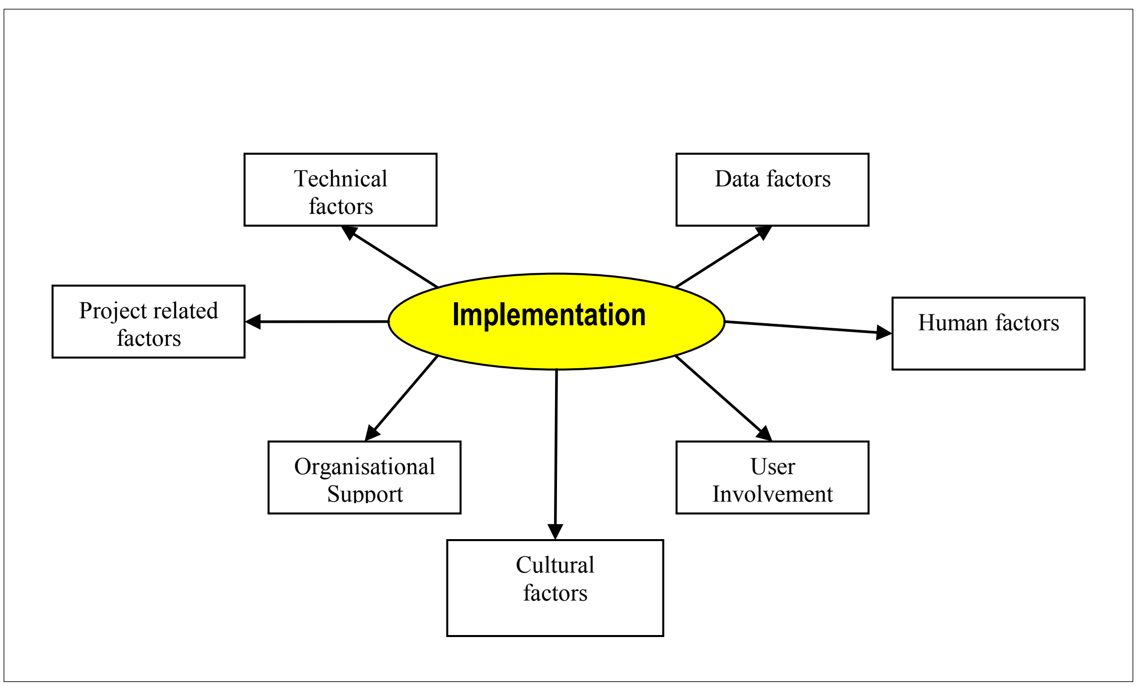
for different crops for example, number of knowledge rules that need to be referred may depend on individual crops. To implement this, an expert system shell can be used instead of MS Access and Visual basic.

9.5 Implementation of "Crop Advisor" expert system

Implementation is defined as a process by which a newly developed or significantly changed system is introduced to users (Turban 1988:580). The implementation process is an iterative process where every stage produces feedback to apply to further improvement of the product. In the current research, the expert system was developed using South Australian data and knowledge. Ultimately, the expert system is for Indian farmers (see section **Error! Reference source not found.**). Accordingly, the issues involved in successfully adopting the expert system for a country like India are discussed.

There are many factors that determine a successful implementation of a new software application, some relevant factors are shown in Figure 9.2 and discussed.

Figure 9.2 Determinants of successful implementation (Adapted from Turban 1988:584)



a. Technical factors

The technical issues associated with implementation can be of two types; technical constraints resulting from limitation of available technology and technical problems that occur due to the scarcity of resources. In India, there will be no problem with the available technology but the scarcity of resources might be a barrier that needs resolution, possibly with some financial support from the governments of developing countries.

b. Data factors

The non-availability of data, data access restrictions, incorrect data and non-availability of timely information are some of the problems that need to be overcome in most developing countries. The data collection procedures need to be established to ensure timely, quality data is collected. Some of these data need to be processed before they could be input into the "Crop Advisor" expert system. These steps can be automated with available GIS software tools.

c. Project related factors

The project needs to be tailored to the actual requirements of users and organisations that are already involved in farmer, community development. Apart from suggesting a best crop, additional crop advices can be included with information on how to grow a crop efficiently and how to market the produce to get a good price. The "Crop Advisor" expert system should be part of a comprehensive agriculture support service for the farmers.

d. Organisational support

Much of the data problems, financial resources can be solved with organisational support. A political will is necessary to take up such a massive project. In countries like India, already, there exist "Village Information Kiosks" which deliver essential weather and market price information to farmers on a daily basis (Lancaster 2003). Crop Advisor can be installed in these village information kiosks so farmers can access the service easily.

e. Cultural factors

There may be doubts among the users about the reliability of expert system's credibility. They may continue to adopt decisions in their own way. The suggestions provided by the "Crop Advisor" expert system should bring profit to users to bring reliability. It would be necessary to involve farmers to ask for their feedback and what do they expect from an agricultural advice system.

f. Human factors

The experts may not co-operate due to a fear of losing their importance and job security. The experts who share their knowledge should be compensated with some incentives. The experts should be assured of their job security; they will also benefit by the sharing of their knowledge.

g. User involvement

The users need to be involved in the knowledge base development stage. Sufficient emphasis must be given to traditional agriculture knowledge and practices that can be included as knowledge rules. Local institutions and agricultural officers who interact with users on a daily basis should be entrusted to do a user-needs survey.

These implementation hurdles can be managed by adopting a set of implementation strategies (Turban 1988:606) including:

- dividing the implementation into manageable stages
- keeping solutions simple
- developing a satisfactory support base
- meeting user needs and institutionalising the system

In the less-developed countries, the development of spatial databases and other supplementary databases will take the bulk of the time and efforts in project implementation stage. However, in some countries like India where, federal and state agencies have defined a national spatial data infrastructure in place and under this most of these natural datasets are being developed. These databases are tailor-made and can become direct inputs for a decision support system such as the 'Crop Advisor'.

9.6 Contributions of the research

In this section the contributions made by the research are reviewed and evaluated. As a theoretical contribution, the research has tested a knowledge-based approach to land evaluation and crop suitability and suggests that this approach has the potential to solve a real-world spatial problem. The research fulfilled the need to extend the regional level land evaluation procedure to provide crop suitability analysis at the farm level. At present, the land use plans in the developing countries are being developed at the farm level and government agencies periodically release strategic land use plan maps which are not being used in the farm level planning processes by farmers. The method used in the research where the use of a strategic, regional land use plan to dictate the land use decision making process at the farm level will benefit the farmers as well as maintaining the environmental balance. The practical contributions of this research include the development of a prototype expert system, "Crop Advisor", that is helpful for farmers by suggesting suitable crops based on land evaluation. Although, the factors incorporated in the knowledge-base could be improved further, the research provided a basic framework on which the system can be expanded to meet user needs. The framework for adding new knowledge into the knowledge bases was established with procedures for easy modifications and updates. The prototype is a pre-cursor for developing a knowledge-based, collaborative land evaluation and land use planning tool.

9.7 Future research directions

The current research proved the workability of a knowledge-based approach to land evaluation and agricultural land use planning of farm units. The next step would be to strengthen it with extensive knowledge bases by collecting detailed knowledge rules on various disciplines and factors associated with land evaluation and land use planning. Instead of a single knowledge-base table used in this research, several different knowledge-base servers can be used as inputs for the expert system. These knowledge base servers can reside at different geographic locations as shown in the Figure 1.1 (Chapter 1), can be linked to a central knowledge base of the expert system. At present, the "Crop Advisor" expert system suggests suitable crop choice for a given time. It can be further developed, with inputs from climate prediction models, to predict future land use choices, what crops would be suitable after five, ten or twenty years, for a land unit based on predicted changes in climate. Additional land uses with their knowledge rules to reflect their land use requirements can be added, so that the functionality of the expert system can be extended to industry site selection, ecological evaluation and impact assessment purposes. The research can be extended to create a web-based expert system that connects with various knowledge bases to access knowledge rules in real-time to deliver agriculture recommendations (Ponnusamy, 2005). This can be achieved by having multiple knowledge bases, one for each scientific discipline, connected by a communication network which would serve the expert system and by this way, human experts can keep knowledge bases updated and accurate. The expert system would access appropriate knowledge bases when a problem demands them. As pointed by Rafea (1998:35-3), such a network of knowledge base servers would remain up-to-date and duplication of expert knowledge at different places can be avoided. This type of web-based expert system can be developed to support users who cannot easily access expertise, expert advice and knowledge from human experts. Such web-based expert systems are necessary in even non-agricultural fields such as Medicine, Law and Finance as the web capability enable to deliver advices and suggestions anytime and anywhere.

9.8 Conclusion

The objective of the research is fulfilled by the development of the “Crop Advisor” expert system which provided a proof-of-concept demonstration for a knowledge-based approach to land evaluation and crop suitability assessment. Though, the developed system is still in a nascent stage, it could be further developed to include more complex factors, knowledge bases and provide more relevant recommendations and crop advices to land owners.

9.9 Summary

The current chapter presented the results of the present study which resulted in the development of “Crop Advisor” expert system prototype. It presented a review on the merits and demerits that exist with the system and presented a few methods on how they can be improved. The chapter presented several strategies and factors that need be taken into account when such an expert system is implemented in the real-world. Finally, it discussed the contributions made by the current study, laid out directions for further research and concluded the thesis.

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Appendix I: Factors used in Physical Land Evaluation by DWLBC

Attribute category	Attribute	Symbol
Topography	Steepness	e
	Surface rockiness	r
	Exposure	y
Waterlogging / salinity / drainage	Susceptibility to waterlogging	w
	Depth to water table	o
	Salinity (induced by water table)	s
	Deep drainage	b
	Recharge potential	q
	Susceptibility to flooding	f
Soil fertility	Inherent fertility	n
	Susceptibility to acidity	h
	Surface carbonate	ka
	Subsoil carbonate	kb
Chemical barriers to root growth	Alkalinity	I
	Dry saline land	v
	Boron toxicity	t_b
	Sodium toxicity (sodicity)	t_{Na}
	Aluminium toxicity	t_{Al}
	Acid sulfate potential	j
Soil depth / water storage	Available water holding capacity	m
	Depth to hard rock	xr
	Depth to hardpan	xp
	Potential root zone depth	
	Sensitive perennial horticultural crops	da
	Intermediate perennial horticultural crops	db
	Hardy perennial horticultural crops	dc
	Annual root crops	dd
	Annual above ground horticultural crops	de
Soil physical conditions	Surface soil condition	c
	Surface texture	-
	Susceptibility to water repellence	u
	Subsoil structure	p
Erosion potential	Water erosion potential	e
	Wind erosion potential	a
	Susceptibility to water repellence	u
	Scalding	z
	Gully erosion	g
	Mass movement (landslip)	l

Appendix II: Factors used in a typical land evaluation and crop suitability analysis process
(Maschmedt, D 2006, pers. comm., May 2006)

Factors used in a typical land evaluation and crop suitability assessment process			
	Topography	*Steepness*	Steepness or the slope gradient is major limiting factor in hilly regions. As agriculture machinery may not negotiate a slope more than 30%, this is an important factor in evaluating farm units that use agriculture machinery in farm operations.
		Surface rockiness	Surface rockiness and rock outcrops make the land non-arable. They further prevent smooth movement of machinery and cause interference and damage to equipment.
		Exposure	Exposure to wind reduces productivity through desiccation, foliar damage and root disturbance. Coastal exposure is a greater limitation than inland exposure because of the additional problem of salt spray.
	Waterlogging / salinity / drainage	*Susceptibility to waterlogging*	Waterlogging affects most crops by reducing or eliminating oxygen supply to the root system, creating favourable conditions for root-rotting anaerobic micro-organisms, and contributing to nitrogen loss. For example, a slowly permeable soil in a dry location may be assessed as well-drained because the rainfall is insufficient to saturate the soil in most seasons. The same soil under irrigation may be susceptible to waterlogging.
		Depth to water table	Depth to water table is estimated as the "shallowest depth maintained for at least two weeks in most years". On a regional scale, this assessment is generally an estimate, and as such can only be used as an indication of a possible limitation in land evaluation. A water table present within the potential root zone affects plant productivity in the same way as waterlogging. Saline water tables are clearly a more severe limitation than those which are non-saline.
		Salinity (induced by water table)	Salinity inhibits capacity of water absorption from the soil. Salt affected plants are often moisture-stressed. Salinity also affects some plants through the toxic effects of sodium and / or chloride. One remedy to this problem is to use salt tolerant crop varieties. This severely restricts cropping options.
		Deep drainage	Deep drainage is the capacity of the deep subsoil and the material immediately underlying the soil profile to transmit water away from the root zone. The situation is complicated where shallow water tables occur, as

			these also restrict downward water movement. Restricted deep drainage prevents leaching of salts, and can thus have an indirect effect on limiting the growth of dryland crops and pastures. However, the main impact of a deep drainage limitation is on irrigated land where the hydrology of the soil profile is significantly altered.
	Soil depth / water storage	*Available water holding capacity*	The water holding capacity of a crop is determined by the amount of water stored in the root zone. It signals the duration that a crop can survive between rain events. In South Australia's climate where rainfall, especially at the opening and the close of the season is erratic, this attribute is critical for the success of dryland crops and pastures. On irrigated land, irrigation scheduling largely overcomes this limitation.
		Depth to hard rock or hardpan	Hard rocks or hardpans are defined as materials that are not penetrable with hand tools, and as such does not support a crop's root growth. Depth to hard rock or hardpan is not used as criteria per se in the land evaluation, but is incorporated into 'available water holding capacity' and 'potential root zone depth' factors.
		Potential rootzone depth	This attribute indicates the "irrigable depth" of the soil profile. It is determined by the depth to restrictive layers such as poorly structured clays, carbonate accumulations and hard rock or pans. Potential root zone depth varies between species, depending on their capacity to penetrate various materials.
	Chemical barriers to root growth	*Alkalinity*	Like acidity, alkalinity affects nutrient availability and uptake. Unlike acidity, alkalinity cannot be corrected (in a commercial situation).
		Dry saline land	Salts which have accumulated in the soil in the absence of water tables have the potential to restrict root growth and hence the efficiency of water-use. In irrigated situations, initial water applications may be used to flush the salts out of the potential root zone, but this can only occur if deep drainage is unrestricted.
		Toxic elements	Toxic elements in the potential root zone effectively limit the depth to which plants can extract moisture and nutrients. In South Australia's agricultural districts, boron and sodium toxicity are widespread, while aluminium toxicity is a problem in acidic soils (invariably in higher rainfall areas). Data on critical concentrations of boron and sodium for crops (other than boron in cereals) is sparse. In the attribute data base linked to the soil landscape mapping, boron toxicity is determined by the depth to concentrations exceeding 15 mg/kg, while sodium toxicity is determined by the depth to exchangeable sodium percentages (ESP) exceeding 25. Aluminium toxicity is determined by the concentration of extractable

			aluminium in the potential root zone.
	Soil Fertility	*Inherent fertility*	This is a subjective assessment of a soil's capacity to store and release nutrients. It is judged by exchangeable cat ion characteristics, clay and organic matter content, leaching capacity, acidification potential, and carbonate and ironstone content. Different species vary in their nutrient requirements - those with lower requirements or more efficient uptake mechanisms perform better on soils of inherently low fertility
		Susceptibility to acidity	Acidity affects the availability of nutrients in the soil, reduces the nutrient retention capacity of the soil, and inhibits the activity of some micro-organisms essential for healthy plant growth. The capacity of root hairs to take up nutrients may also be reduced in acidic soils, partly due to damage caused by aluminium, the solubility of which increases at lower pH (see aluminium toxicity). Susceptibility to acidity is determined through a combination of actual measurements and extrapolation between similar soil landscape environments.
		Soil carbonates	Fine earth carbonates at shallow depth in the soil affect nutrient availability and uptake. Carbonate effects become significant when concentrations exceed more than 10%.
	Soil physical conditions	*Surface soil condition*	The condition or strength of the soil surface affects water infiltration, workability, seedling emergence and erodability. Loose to friable surface soils present few problems for any crop. Hard setting soils are more susceptible to problems, while dispersive soils are highly susceptible to damage and restrict plant growth.
		Surface texture	Surface texture is used in some crop potential assessments either as an additional means of downgrading low fertility sandy soils, or to downgrade clayey surfaces which are undesirable for root crops.
		Susceptibility to water repellence	Water repellence affects crop establishment and increases the risk of both wind and water erosion, and sand blasting. It is less of a limitation in irrigated crops than in rain fed situations because amelioration is simpler.
		Subsoil structure	The nature of the subsoil affects water movement and root growth. Structural characteristics, strength and depth are the determinants of the degree to which subsoil materials impact on root growth and permeability. The effects of unfavourable subsoil structure are reflected in other attributes, mainly 'susceptibility to waterlogging', 'available water holding capacity' and 'potential root zone depth'.
		Water erosion potential	In hilly country, slope gradient is a key determinant of land class. Any uses involving cultivation are not possible on slopes steeper than 30%. In reality, the risk of erosion generally sets the upper slope limit at 20%

			for cultivated land uses, but slopes steeper than 8-12% (depending on soil erodibility) require very high levels of conservation management. Perennial crops and pastures can be managed on steeper slopes, but erosion potential and practicability / safety issues cause steep slopes to be down-graded for all uses. Unchecked erosion causes loss of nutrients and organic matter (which are concentrated in the upper few cm), and loss of soil depth and structure. Consequently sloping land has a higher degree of limitation for annual crops than it does for perennial crops and pastures.
	Erosion potential	*Wind erosion potential*	The potential for wind erosion is a critical determinant of land class in sandy regions. Wind erosion is responsible for substantial losses of nutrients and organic matter, and loss of soil depth. Consequently, wind erosion-prone land has a higher degree of limitation for annual crops than it does for perennial crops and pastures.
		Scalding	Scalding is the exposure of inhospitable subsoils by erosion in the past. It reduces productive potential by reducing arable area. Land susceptible to scalding is fragile and requires conservative management.
		Gully erosion	Apart from their land degradation aspects, erosion gullies affect accessibility and hinder the installation and use of irrigation systems. Land is assessed according to the proportion affected by gullying - all crop types are affected to similar degree.
		Mass movement (landslip)	Land affected by or prone to mass movement is usually too steep for cropping, but generally has some potential for grazing or perennial horticulture.
		Water quality	Quality and quantity of water supplies are essential considerations when assessing potential for irrigated crops. Although strictly not a soil or landscape attribute, water resource data, where available, are generally incorporated into an assessment of potential for irrigated crops. If the water quality is severely low, the land is classified according to the water quality class rather than any limitations imposed by soil or landscape features.
		Climate and rainfall	The daily temperature, evaporation rate and rainfall affect the crop decision widely. The amount of rainfall, number of rainy days and the season of rainfall are the crucial factors for dryland crops. Both the historical averages as well as future forecasts should be consulted before a crop decision is made.
		Size and nature of land	The size and shape of a farm unit may affect what crop can be grown there. Large farms are most suitable for mechanized farming. The size of the farm should be

			large enough to compensate the investment in the farm machinery.
		Profitability (Costs/Returns)	The return from the crop yield must exceed the cost of cultivating the crop, if not it would be a loss for a cultivator.
		Market Price and Demand for a crop	The price of crop produce at markets is an essential element that drives the choice of crop. Also, the seasonal demand for the particular produce should be considered before selecting a crop. The selection of crops, which prices of the crop produces are highly fluctuating in the market place, tend to be risky.
		Access to Market	The access to transport network, nearest grain storage points, freezer plants and railway stations influence crop decisions as they indicate the possibility of transporting and storing crop produces in a much easier way.
		Access to Water / Water Price	The water required for irrigation has to be purchased in some regions. Hence, the price of water needs be too taken into account.
Suitability based on other factors			
		Crop Rotation	The previous year's crop affects the productivity of a farm unit. Growing same crop year-after-year not only robs the productivity of the soil, but also it does not break the pests' life cycle. Crop rotation is successful alteration of crops preferable from two dissimilar families of crops.
		Equipment & Labour	Some crops can be seeded, harvested with the help of farm machineries but others don't permit. Horticultural crops usually involve labour-intensive farming methods. On the other hand, with the help of machineries, large fields of wheat or canola can be managed with ease.
		Government policies and restrictions	The government indirectly controls agricultural crops grown in a certain region by providing favourable subsidies, offering fare prices and establishing procurement prices for certain crops. On the other hand, it also restricts the growth of certain crops by the method of licensing, water restrictions and imposing zoning regulations.
		Environmental factors	Sometimes, environmental factors such as the geographical location of a farm unit may influence farmer to choose or not to choose a crop.

Appendix III

Appendix III: List of Crop Choices (Maschmedt, D 2006, pers. comm.)

S.No.	Crop	Code	Crop Family
1.	Almond	ALMONDS	Horticulture
2.	Apple	APPLES	Horticulture
3.	Barley	BARLEY	Cereal
4.	Brassicas	BRASSICAS	Annual horticulture
5.	Canola	CANOLA	Oilseeds
6.	Carrot	CARROTS	Root crops
7.	Cherry	CHERRIES	Horticulture
8.	Chickpea	CHICKPEAS	Grain legume
9.	Citrus	CITRUS	Horticulture
10.	Field Pea	FIELDPEAS	Grain legume
11.	Faba Beans	FABABEANS	Grain legume
12.	Grapevine	GRAPES	Horticulture
13.	Grapevine Medium	GRAPESMH	Horticulture
14.	Grasses	GRASSESDR	Pasture
15.	Grazing	GRAZINGDR	Pasture grass
16.	Lavender	LAVENDER	Flower
17.	Lentil	LENTILS	Grain legume
18.	Legumes	LEGUMESDR	Pasture legume
19.	Lucerne Dryland	LUCERENEDR	Pasture legume
20.	Lucerne Irrigated	LUCERENEIR	Pasture legume
21.	Lupin	LUPINS	Grain legume
22.	Maize	MAIZE	Forage
23.	Oats	OATS	Cereal
24.	Olive	OLIVES	Horticulture
25.	Onion	ONIONS	Root crops
26.	Summer Fodder	PASTURE	Forage
27.	Pear	PEARS	Horticulture
28.	Phalaris Dryland	PHALARISD	Pasture grass
29.	Potato	POTATOES	Root crops
30.	Pyrethrum	PYRETHRUM	Specialty crop
31.	Perennial Rye Grass Dryland	RYEGRASSD	Pasture grass
32.	Perennial Rye Grass Irrigated	RYEGRASSH	Pasture grass
33.	Strawberry Clover	STCOLVER	Pasture legume
34.	Subterranean Clover	SUBCLOVER	Pasture legume
35.	Triticale	TRITICALE	Cereal
36.	Wheat	WHEAT	Cereal
37.	White Clover Irrigated	WHITECLOV	Pasture legume

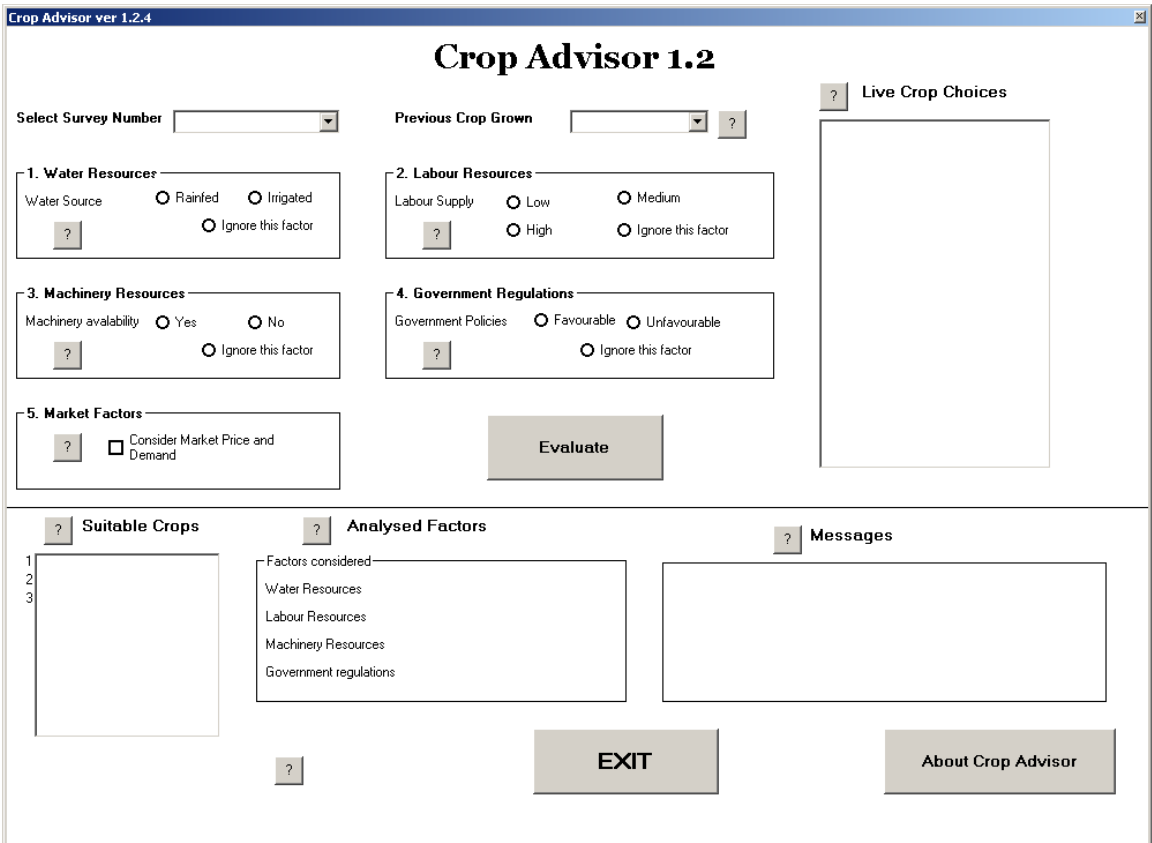
Appendix IV: Criteria for assessing land suitability for Canola crop as developed by DWLBC (DWLBC 2003a)

Land quality		What to measure or look for	Degree of limitation				
			Negligible Class 1	Slight Class 2	Moderate Class 3	High Class 4	Severe Class 5
Waterlogging	w	Length of time that any part of the profile is saturated following heavy rain.	< 1 week w = 1,2	1-2 weeks (early) w = 3	Several weeks w = 4	Several mths w = 5	Most of year w = 7,8
Depth to water table	o	Estimate highest level maintained for at least two weeks per year					
		Where s = 1	>100 cm o = 1,2	50-100 cm o = 3	-	0-50 cm o = 4	Above surf o = 5, 7, 8
		Where s = other than 1 (includes 1o, 1+, 1x)	> 200 cm o = 1	100-200 cm o = 2	50-100 cm o = 3	0-50 cm o = 4	Above surf. o = 5, 7, 8
Water holding capacity	m	Estimate mm total available water in root zone	>100 mm m = 1	70-100 mm m = 2	40-70 mm m = 3	20-40 mm m = 4	<20 mm m = 5
Salinity (associated with water table)	s	Observe presence of halophytic plants (eg sea barley grass) **OR**	None present	None present but subsoil is mod. saline	Scattered halophytes	Halophytes common	Mostly halophytes
		Measure ECe (dS/m) in surface and subsoil	< 2 (surface) < 4 (subsoil) s = 1	2 - 4 (surf) 4 - 8 (subs'l) s = 2	4 - 8 (surf) 16 (subs'l) s = 3	8-16 (surf) 16-32(subs'l) s = 4	>16 (surf) >32 (subs'l) s = 5,7,8
		If w =4,5,7,8	s = 1	-	s = 2	s = 3	s = 4,5,7,8
Patchy salinity (associated with water table)	s	Proportion of land affected by saline seepages	<2% "s" subs't =o **or** absent	2-10% "s" subs't = +	10-50% "s" subs't = x	-	-
Dry saline land	v	Measure ECe (dS/m) in surface and subsoil.	< 2 (surface) < 4 (subsoil) v = 1	2 - 4 (surf) 4 - 8 (subs'l) v = 2	4 - 8 (surf) 8 - 16 (subs'l) v = 3	8 - 16 (surf) 16-32 (subs'l) v = 4	>16 (surf) > 32 (subs'l) v = 7
Patchy dry saline land	v	Proportion of land affected by dry saline (magnesia) patches	<2% "v" subs't = o **or** absent	2-10% "v" subs't = +	10-50% "v" subs't = x	-	-
Acidity	h	Measure pH $CaCl_2$ at surface & deep subsoil: Surface > Subsoil 1 = > 5.4 1= > 6.9 2,3 = 4.5 - 5.4 2 = 5.5 - 6.9 4,5 = < 4.5 3 = 4.5 - 5.4 4 = < 4.5	h = 1> *, 2>1, 2>2, 2>3	h = 2>4, 3>*	h = 4>*, 5>*	-	-
		Downgrade if aluminium present (ta = 2 or 3):	h = 1>*	h = 2>1, 2>2, 2>3	h = 2>4, 3>*	h = 4>*, 5>*	-
Alkalinity	i	Measure pH (water) at surface & deep subsoil: Surface > Subsoil 1 = < 8.0 1 = < 8.0 2 = 8.0 - 9.2 2 = 8.0 - 9.2 3 = > 9.2 (10-30) 3 = > 9.2 4 = > 9.2 (0-10)	i = 1>1, 1>2, 2>2	i = 1>3, 2>3	i = 3>3	i = 4>3	-
Surface CO_3	ka	Reaction to 1M HCl	Nil to mod. ka = 1,2	Strong ka = 3	-	-	-
Subsoil CO_3	kb	Depth to strong reaction to 1M HCl	>30 cm kb = 1,2	< 30 cm kb = 3	-	-	-
Inherent fertility	n	Identify soil type	High, v. high n = 1	Moderate n = 2	Mod. low n = 3	Low n = 4	Very low n = 5
Toxic elements	tb	Determine depth to boron levels of > 15 mg/kg	>100 cm tb = 1	50-100 cm tb = 2	25-50 cm tb = 3	10-25 cm tb = 4	<10 cm tb = 5
	ts	Determine depth to exchangeable sodium percentage of > 25%	>50 cm ts = 1,2	25-50 cm ts= 3	10-25 cm ts = 4	-	<10 cm ts = 5
Rockiness	r	Estimate proportion of surface rock and stone	Nil - slight r = 1,2	Picking or rolling r = 3	Semi arable r = 4	-	Non arable r = 5, 6, 8

Land quality		What to measure or look for	Degree of limitation				
			Negligible Class 1	Slight Class 2	Moderate Class 3	High Class 4	Severe Class 5
Surface condition	c	Hardness / dispersiveness of surface soil	Loose, soft, friable c = 1	Hard c = 2	Dispersive c = 3	Str. dispersive c = 4	-
Subsoil structure	p	Determine depth to and nature of subsoil. eg Depth to dispersive clay:	> 30 cm p = 1,2	20-30 cm p = 3	10-20 cm p = 4	<10 cm p=5	-
Scalding	z	Assess the percentage of land affected	None z = 1	Up to 5% z = 2	5 - 10% z = 4	10 - 50% z = 5	> 50% z = 7
Water repellence	u	Measure time taken for drop of water to be absorbed into soil	Non repellent u = 1	Repellent u = 2	Strongly repellent u = 3	-	-
Water erosion potential	e	Refer handbook for water erosion classes	Low - mod low e = 1,2	Moderate e = 3	Mod. high e = 4	High e = 5	Very high - extreme e = 6,7
Wind erosion potential	a	Refer handbook for wind erosion classes	Low - mod low a = 1,2	Moderate a = 3	Mod. high a = 4	High a = 5	Extreme a = 7
Gully erosion	g	Assess percentage of land affected	< 5% g = 1,2	5-10% g = 3	10-20% g = 4	-	>20% g = 7, 5x,7x
Mass movement	l	Estimate area affected or at risk	None present l = 1	-	None present (potential) l = 4	Up to 5% of land affected l = 5	> 5% of land affected l = 7
Exposure	y	Estimate degree of wind exposure	Nil y = 1	Moderate y = 2	High (coast) y = 3	-	-

Appendix V: Source code of the "Crop Advisor" Expert System

1 Code for main screen of "Crop Advisor" (frmMain)




```
Option Explicit


Dim Conn1 As New ADODB.Connection
    Dim Cmd1 As New ADODB.Command
    Dim Errs1 As Errors
    Dim Rs1 As New ADODB.Recordset
    Dim str1, str2, str3, str4 As String
    Dim previous_crop  As String

    Dim AccessConnect As String

    ' Error Handling Variables
    Dim couter_loop    As Integer


    Dim strTmp As String
    Dim maincrop As Variant
    Dim afterwater As Variant
    Dim afterlab  As Variant
    Dim aftermach As Variant
```

```
    Dim aftergov As Variant
    Dim crops_name As Variant



    Dim rainfed_data As Variant
    Dim Irrigated_data As Variant
    Dim lab_high_data As Variant
    Dim farm_crops As Variant
    Dim lab_med_data As Variant
    Dim lab_low_data As Variant
    Dim mach_yes_data As Variant
    Dim mach_no_data As Variant
    Dim gov_fav_data As Variant
    Dim gov_Unfav_data As Variant

    Dim crops_limit   As Integer
    Dim crops_manipulation() As String
    Dim temp_str() As String

    Dim errLoop As Error


Private Sub c1_Click()

Dim survey As String
survey = c1.Text

Dim i As Integer
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
  ' Conn1.ConnectionString = AccessConnect
  ' Conn1.Open AccessConnect
   Set Rs1 = Conn1.Execute("SELECT *From farm WHERE DCDB_ID= '" & c1.Text & "' ")

    crops_limit = (Rs1.Fields.Count - 2)



   l1.Clear

     Do Until Rs1.EOF
     ' Rs1.MoveFirst
      For i = 1 To (Rs1.Fields.Count - 1)
       l1.AddItem "" & Rs1(i)
      Next i
      Rs1.MoveNext

    Loop
    Rs1.MoveFirst

     maincrop = Rs1.GetRows
```

```
   ReDim temp_str(crops_limit) As String

   For i = 1 To crops_limit
       temp_str(i) = maincrop(i, 0) & ""
   Next i

     farm_crops = temp_str


     Rs1.Close
      Conn1.Close


End Sub



Private Sub Combo1_Click()
previous_crop = Combo1.Text

End Sub

Private Sub Command1_Click()
results.Clear
couter_loop = 0
Dim i, j As Integer
usedcrop.Caption = ""
  AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
If mrkp.Value = 1 Then




   Dim Rs2 As New ADODB.Recordset
   Set Rs2 = Conn1.Execute("SELECT Crop, Code FROM crop ORDER BY price DESC")
   Do Until Rs2.EOF

   couter_loop = couter_loop + 1
   Rs2.MoveNext
   Loop

  Rs2.MoveFirst
  crops_name = Rs2.GetRows
  Rs2.Close



Dim mesage As String
mesage = " You have recently grown this crop - "

For i = 0 To couter_loop - 1
  For j = 0 To crops_limit - 1
```

```
   If aftergov(j) = crops_name(1, i) Then
    If previous_crop = crops_name(0, i) Then

     results.AddItem "" & crops_name(0, i)
     usedcrop.Caption = mesage + crops_name(0, i)
    Else

    results.AddItem "" & crops_name(0, i)

   End If

  End If
  Next j
Next i

Else
results.Clear


   Set Rs2 = Conn1.Execute("SELECT Crop, Code FROM crop ")
   Do Until Rs2.EOF
    couter_loop = couter_loop + 1
    Rs2.MoveNext
   Loop

  Rs2.MoveFirst
  crops_name = Rs2.GetRows
  Rs2.Close

mesage = "  You have recently grown this crop - "

For i = 0 To crops_limit - 1
  For j = 0 To couter_loop - 1
   If aftergov(i) = crops_name(1, j) Then
    If previous_crop = crops_name(0, j) Then

     results.AddItem "" & crops_name(0, j)
     usedcrop.Caption = mesage + crops_name(0, j)
    Else

    results.AddItem "" & crops_name(0, j)

   End If

  End If
  Next j
Next i
End If
wrr.Caption = str1
lrr.Caption = str2
mrr.Caption = str3
Grr.Caption = str4
Conn1.Close
End Sub

Private Sub Command10_Click()
```

```
MsgBox "If the previous or current crop shows up in the Suitable Crops list, a message will appear.", vbExclamation,
"Warning"
End Sub

Private Sub Command11_Click()
MsgBox "As you select / change the factors and options, the crop choices will change automatically", vbExclamation,
"Live Choices"
End Sub

Private Sub Command12_Click()
MsgBox "The crop which was grown last year in the farm you selected. Or the current crop", vbExclamation, "Previous
Crop"
End Sub

Private Sub Command13_Click()
Load frmAbout
frmAbout.Show
End Sub

Private Sub Command2_Click()
MsgBox "Choose whether your farm depends on Rainwater or Irrigated water crop for raising crops. Some crops
require irrigation!", vbExclamation, "Water Availability"
End Sub

Private Sub Command3_Click()
MsgBox "Choose the amount of labour available or how much labour you can supply", vbExclamation, "Labour
Availability"
End Sub

Private Sub Command4_Click()
MsgBox "Choose if you have available Machinery or if you can hire Machinery", vbExclamation, "Machinery
Availability"
End Sub

Private Sub Command5_Click()
MsgBox "Choose if want to include Government induced factors in the Crop Suitability analysis", vbExclamation, "Govt.
Regulations"
End Sub

Private Sub Command6_Click()
MsgBox "Choose if you would like to consider current Market Price and Market Demand for making cropping
decisions", vbExclamation, "Market Factors"
End Sub

Private Sub Command7_Click()
MsgBox "Suitable crops for your farm unit based on the factors you chose to analyze.Most suitable crop is listed on
Top", vbExclamation, "Suitable Crops"
End Sub

Private Sub Command8_Click()
MsgBox "The factors chosen by you that are considered for Evaluation", vbExclamation, "Analysed Factors"
End Sub

Private Sub Command9_Click()
MsgBox "A message will be displayed below if the Expert System ran out of choices", vbExclamation, "Message"
End Sub
```

```
Private Sub Form_Load()
  AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
   Dim Rs2 As New ADODB.Recordset
   Set Rs2 = Conn1.Execute("SELECT DCDB_ID FROM farm")

    Do Until Rs2.EOF
      c1.AddItem "" & Rs2("DCDB_ID")
      Rs2.MoveNext
    Loop

       Rs2.Close


        Set Rs2 = Conn1.Execute("SELECT Crop FROM crop")

    Do Until Rs2.EOF
      Combo1.AddItem "" & Rs2("Crop")
      Rs2.MoveNext
    Loop

       Rs2.Close
       Conn1.Close



End Sub


Private Sub Help_Click()
Unload fMainForm
End Sub

Private Sub irrigated_Click()
Dim Rs_irrigated As New ADODB.Recordset
couter_loop = 0
str1 = "Irrigated"
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect


   Set Rs_irrigated = Conn1.Execute("select Code from crop where Water ='Irrigated'")


   Do Until Rs_irrigated.EOF

   couter_loop = couter_loop + 1
   Rs_irrigated.MoveNext
   Loop
```

```
   Rs_irrigated.MoveFirst

   Irrigated_data = Rs_irrigated.GetRows


   Rs_irrigated.Close
   Conn1.Close


  Call crops_compare(farm_crops, Irrigated_data)
     afterwater = crops_manipulation
     Call display_crops_listbox(afterwater)
End Sub

Private Sub labhigh_Click()

Dim Rs_labhigh As New ADODB.Recordset
couter_loop = 0

str2 = "Labour High"
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect


   Set Rs_labhigh = Conn1.Execute("select Code from crop where Labour ='Low' or Labour ='Medium' or Labour
='High'  ") '

   Do Until Rs_labhigh.EOF

   couter_loop = couter_loop + 1
   Rs_labhigh.MoveNext
   Loop


  Rs_labhigh.MoveFirst
 lab_high_data = Rs_labhigh.GetRows
 Rs_labhigh.Close
 Conn1.Close

 Call crops_compare(afterwater, lab_high_data)
afterlab = crops_manipulation
Call display_crops_listbox(afterlab)

End Sub

Private Sub labignore_Click()
afterlab = afterwater
Call display_crops_listbox(afterlab)
str2 = " The Labour Factor is Ignored"
End Sub

Private Sub lablow_Click()
Dim Rs_lablow As New ADODB.Recordset
```

```
couter_loop = 0
str2 = "Labour Low"
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
   Set Rs_lablow = Conn1.Execute("select Code from crop where Labour ='Low'  ")

   Do Until Rs_lablow.EOF

   couter_loop = couter_loop + 1
   Rs_lablow.MoveNext
   Loop


  Rs_lablow.MoveFirst
 lab_low_data = Rs_lablow.GetRows
 Rs_lablow.Close
 Conn1.Close

 Call crops_compare(afterwater, lab_low_data)
afterlab = crops_manipulation
Call display_crops_listbox(afterlab)
End Sub

Private Sub labmed_Click()
Dim Rs_labmed As New ADODB.Recordset
couter_loop = 0
str2 = "Labour Medium"
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect


   Set Rs_labmed = Conn1.Execute("select Code from crop where Labour ='Low' or Labour ='Medium'  ")

   Do Until Rs_labmed.EOF

   couter_loop = couter_loop + 1
   Rs_labmed.MoveNext
   Loop


  Rs_labmed.MoveFirst
 lab_med_data = Rs_labmed.GetRows
 Rs_labmed.Close
 Conn1.Close

 Call crops_compare(afterwater, lab_med_data)
afterlab = crops_manipulation
Call display_crops_listbox(afterlab)
End Sub
```

```
Private Sub mach_ignore_Click()
aftermach = afterlab
Call display_crops_listbox(aftermach)
str3 = "Factor ignored"
End Sub

Private Sub mach_no_Click()
Dim Rs_machno As New ADODB.Recordset
couter_loop = 0
str3 = "No"
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
   Set Rs_machno = Conn1.Execute("select Code from crop where Machinery ='No'  ")

   Do Until Rs_machno.EOF

   couter_loop = couter_loop + 1
   Rs_machno.MoveNext
   Loop


  Rs_machno.MoveFirst
 mach_no_data = Rs_machno.GetRows
 Rs_machno.Close
 Conn1.Close

 Call crops_compare(afterlab, mach_no_data)
aftermach = crops_manipulation
Call display_crops_listbox(aftermach)
End Sub

Private Sub mach_yes_Click()
Dim Rs_machyes As New ADODB.Recordset
couter_loop = 0
str3 = "Yes"
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
   Set Rs_machyes = Conn1.Execute("select Code from crop where Machinery ='Yes'  ")

   Do Until Rs_machyes.EOF

   couter_loop = couter_loop + 1
   Rs_machyes.MoveNext
   Loop


  Rs_machyes.MoveFirst
 mach_yes_data = Rs_machyes.GetRows
 Rs_machyes.Close
 Conn1.Close

 Call crops_compare(afterlab, mach_yes_data)
```

```
aftermach = crops_manipulation
Call display_crops_listbox(aftermach)


End Sub

Private Sub Option1_Click()

aftergov = aftermach
Call display_crops_listbox(aftergov)
str4 = "Factor ignored"

End Sub

Private Sub Option11_Click()
Dim Rs_govfav As New ADODB.Recordset
couter_loop = 0
str4 = "Favourable"
'AccessConnect = "Driver={Microsoft Access Driver (*.mdb)};" & _
'                  "Dbq=data.mdb;" & _
'                  "DefaultDir=F:\Exerpertsystem;" & _
'                  "Uid=Admin;Pwd=;"
'   Conn1.ConnectionString = AccessConnect
 '  Conn1.Open AccessConnect
  AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
   Set Rs_govfav = Conn1.Execute("select Code from crop where gov ='Favourable'  ")

   Do Until Rs_govfav.EOF

   couter_loop = couter_loop + 1
   Rs_govfav.MoveNext
   Loop


  Rs_govfav.MoveFirst
 gov_fav_data = Rs_govfav.GetRows
 Rs_govfav.Close
 Conn1.Close

 Call crops_compare(aftermach, gov_fav_data)
aftergov = crops_manipulation
Call display_crops_listbox(aftergov)

End Sub

Private Sub Option12_Click()
Dim Rs_govfav As New ADODB.Recordset
couter_loop = 0
str4 = "Unfavourable"
 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect
```

```
  Set Rs_govfav = Conn1.Execute("select Code from crop where gov ='Unfavourable'  ")

  Do Until Rs_govfav.EOF

  couter_loop = couter_loop + 1
  Rs_govfav.MoveNext
  Loop


 Rs_govfav.MoveFirst
 gov_Unfav_data = Rs_govfav.GetRows
 Rs_govfav.Close
 Conn1.Close

 Call crops_compare(aftermach, gov_Unfav_data)
aftergov = crops_manipulation
Call display_crops_listbox(aftergov)
End Sub

Private Sub rainfed_Click()
Dim Rs_rainfed As New ADODB.Recordset
couter_loop = 0

str1 = " Rainfed"

 AccessConnect = "PROVIDER=Microsoft.Jet.OLEDB.4.0; Data Source= " & _
App.Path & "\data.MDB"
Set Conn1 = New ADODB.Connection
Conn1.Open AccessConnect


  Set Rs_rainfed = Conn1.Execute("select Code from crop where Water ='Rainfed'")

  Do Until Rs_rainfed.EOF

  couter_loop = couter_loop + 1
  Rs_rainfed.MoveNext
  Loop

  Rs_rainfed.MoveFirst


  rainfed_data = Rs_rainfed.GetRows

  Rs_rainfed.Close
  Conn1.Close


 Call crops_compare(farm_crops, rainfed_data)
   afterwater = crops_manipulation
   Call display_crops_listbox(afterwater)

End Sub
Private Sub crops_compare(var1 As Variant, var2 As Variant)

Dim i As Integer
```

```
Dim j As Integer
Dim counter As Integer
ReDim crops_manipulation(crops_limit) As String
counter = 0

    For i = 0 To couter_loop - 1
      For j = 0 To crops_limit
        If var1(j) = var2(0, i) Then
          crops_manipulation(counter) = var1(j)
          counter = counter + 1
        End If
      Next j
    Next i


  If counter = 0 Then
   warning.Caption = " Please reconsider your options because the system has run out of crop choices"

   Else
   warning.Caption = ""
  End If
End Sub

Private Sub display_crops_listbox(var1 As Variant)
l1.Clear

Dim i As Integer

For i = 0 To crops_limit
 l1.AddItem "" & var1(i)
Next i

End Sub

Private Sub waterignore_Click()
str1 = "Water factor is ignored"
ReDim temp_str(crops_limit) As String
Dim i As Integer
For i = 1 To crops_limit
 temp_str(i) = maincrop(i, 0) & ""
Next i

afterwater = temp_str

Call display_crops_listbox(afterwater)
End Sub
```

2 frmAbout (About Screen of "Crop Advisor" Expert System)


```
Option Explicit

Private Sub cmdOK_Click()
  Unload Me
End Sub
```

3 frmSplash (Splash Screen for "Crop Advisor" Expert System)

```
Option Explicit
'Set timer to unload splash screen after a certain time frame.
Private Sub Timer1_Timer()
Unload Me
fMainForm.Enabled = True
End Sub
```

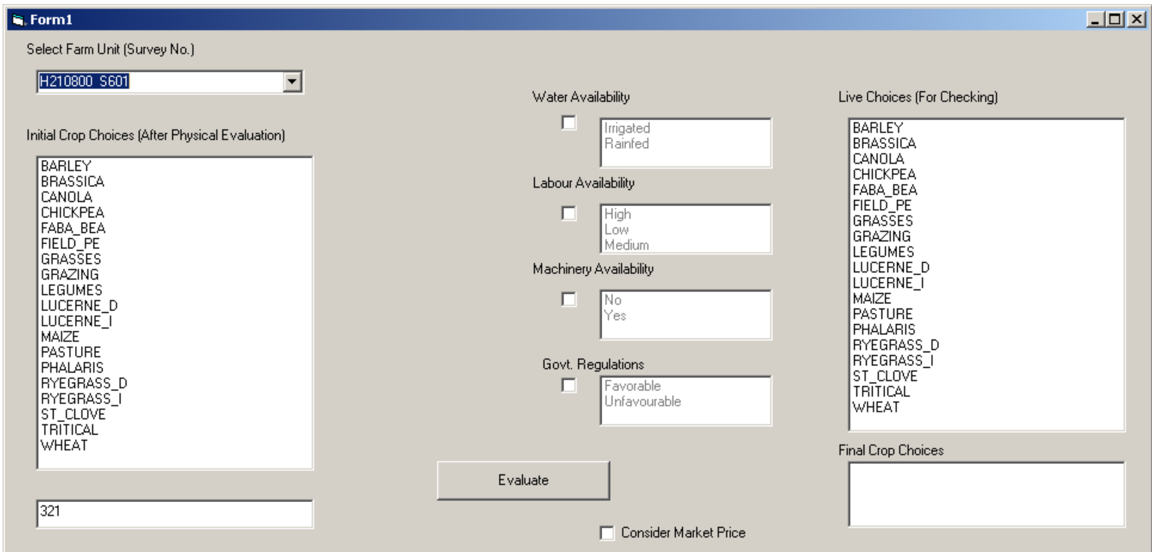
4 Module1 (Startup module)

```
Public fMainForm As Form1

Sub Main()
   frmSplash.Show
   frmSplash.Refresh
   Set fMainForm = New Form1
   Load fMainForm
   Unload frmSplash
   fMainForm.Show
End Sub
```

Appendix VI: Screenshots of the "Crop Advisor" Expert System version 1.0

Main screen of "Crop Advisor" 1.0



Executing "Crop Advisor" 1.0