AN ABSTRACT OF THE THESIS OF

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Title: Development of An Expert System for Irrigation and Fertilization Management in the Pacific Northwest

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Recent advances in computer technology have made possible the development of expert systems. Expert systems are computer programs that perform at the level of a human expert. Expert systems can help integrate and apply diverse sources of information and expertise to problems of integrated crop management. A prototype Crop Management eXpert (CMX) system has been developed. The primary goal of CMX is to provide recommendations on optimal irrigation and fertilization scheduling for wheat production in the Pacific Northwest. This system can be used by farmers and/or extension agents. OUS||Shell has been used as a implementation tool. To build this rule - based expert system, a development strategy, commonly used in the construction of expert systems, consisting of 1) identification; 2) conceptualization; 3) formalization; 4) implementation; and 5) testing was applied.

CMX is composed of modules for irrigation and fertilization management. For irrigation management, CMX is mainly involved in the irrigation scheduling which is the major part of irrigation management. Irrigation strategies have been applied in irrigation decision making. For each strategy, timing criteria which generally consist of management allowed depletion, soil water potential, leaf water potential, and water stress indices have been used. The system provides farmers with irrigation scenarios which determine when and how much water to apply.

CMX represents an integration of conventional computing and expert systems technology designed to provide expert recommendations enabling farmers to obtain the best return on their water and fertilizer investment. For fertilization management, a variety of variables have been taken into considered. Crop growth stages, soil moisture, nutrient analysis, protein requirement, and application methods are important factors for the fertilizer decision making. Several constraints have been used in optimal fertilizer advice.

CMX can focus only on relevant information, thus reducing the problem space to a manageable size and significantly, improving the efficiency of the system. The facility of the expert system to explain the decision-making process enables users to better understand the underlying assumptions, facts, and reasoning used to generate recommendations. The CMX prototype demonstrates the feasibility of employing expert systems technology in agricultural applications.

CMX has been validated and evaluated. The survey results showed that this prototype was successful in capturing domain experts' knowledge as rules and providing advice on the irrigation and fertilization management for wheat.

Development of An Expert System for Irrigation and Fertilization Management in the Pacific Northwest

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DEVELOPMENT OF AN EXPERT SYSTEM FOR IRRIGATION AND FERTILIZATION MANAGEMENT IN THE PACIFIC NORTHWEST

1. INTRODUCTION

In the recent years, major emphasis has been placed on the development of methods to optimize productive potential and increase the profitability of farming. The major challenge facing agriculture today is to keep pace with the increasing food needs for an increasing world population while agricultural land area steadily decreases (Pair et al., 1983). The optimization of farming operations includes maximizing productive potential while also minimizing the costs associated with production. Today and in the future, the proper irrigation and fertilizer management can prove to be very beneficial for both.

Irrigation management has changed dramatically during the past half decade. Irrigation management consists of determining when to irrigate, the amount to apply at each irrigation and during each stage of plant growth, and the operation and maintenance of the irrigation system. The primary management objective is to manage the production system for maximal profit without compromising the environment. The major management activity involves irrigation scheduling; i.e., determining when and how much water to apply (Hoffman et al.,1990). Considerable research on irrigation system and management strategies has been done.

Fertilization is probably the most important means for increasing yields in irrigated agriculture. The subject of fertilization is becoming increasingly complex, so that a knowledge of fertilizers and their uses becomes steadily more important. Fertilization for the sake of high yields can no longer be routinely undertaken according to simple rules, but must be carried out according to extended and improved concepts, as overall production conditions change. Basic fertilization management involves determining what kind of fertilizer to apply, when and how to apply, and the amount to apply at each fertilization.

Water and nutrient in the soil/plant environment are crucial to successful crop production management. As water usage and quality issues become increasingly important, more sophisticated methods for monitoring, controlling and conserving water movement and nutrient uptake are needed. Such methods must consider crop requirements, fertilizer and pesticide transport through the soil, cropping methodology, observed and expected weather, expected crop yields and crop value, water and fertilizer costs, and environmental impacts. Because of the complexity of the interactions between these various factors, improved tools for managing this complexity in real-time in a highly useable manner are needed.

Within the last several years, a number of tools have become available for assisting in this task. Many methods for determining when to irrigate and the amount to apply have been developed and field tested. Some methods require instruments for sensing soil or plant water levels that indicate soil water deficits or plant water stress. Others use simulation models encoding relationships between crops growth and development, soil water uptake and transport, plant nutrient and climatic factors to provide accurate prediction of these variables on crop yield. Similarly, instrumentation for effectively monitoring plant, soil and weather conditions within individual fields has become available at reasonable costs.

Expert Systems (ESs) have advantages over conventional programming techniques that allow for detailed explanation of reasoning procedures, utilization of incomplete and uncertain data, and utilization of experiential knowledge (Waterman,1986). ESs are computer programs that perform at the level of human experts in a limited domain. ESs have been regarded as a mechanism to transfer information to the farmer in an integrated and interpreted characterized by incomplete data and heuristic data (Clarke et al., 1987; Halterman et al., 1988) and also to train and educate individuals to solve new tasks (Engel and Beasley, 1987).

Recent developments in ESs have given agriculture researchers and scientists new ways of transferring expert knowledge and providing decision support to producers (Barrett et al., 1985; Huggins et al., 1986). ESs provide one method for integrating diverse knowledge sources in a highly user-oriented environment to generate optimal management plans. Such an expert system would contain knowledge about current management practices, running the simulation model, interpreting model output, managing real-time and predicted weather and soil conditions databases and constraints on water and fertilizers usage. By combining knowledge contained from these sources, the resulting expert system should be able to provide day-to-day monitoring of crop condition as well as provide recommendations on optimal irrigation and fertilization scheduling.

Initial work in this study is involved in developing an expert system which is able to give advice on optimal irrigation and fertilization scheduling. The overall objective of this research is to develop an expert system for providing preliminary information on feasible irrigation and fertilization management for a site-specific situation in the Pacific Northwest. Users of the system would be farmers and/or extension agents planning an irrigation and fertilization development. The specific objectives of this study are:

1. Develop an expert system containing extensive expert knowledge to provide advice on managing and scheduling irrigation and fertilizer applications for wheat production in the Pacific Northwest.
2. Implement and evaluate this system in the field to determine the effectiveness of the system as a technology transfer tool.

2. LITERATURE REVIEW

The potential of ESs to provide support for agricultural decision problems is widely recognized (Jones, 1985, McKinnion and Lemmon, 1985, Palmer,1986, Stone et al., 1986b). ESs have been used for crop management (Stone et al., 1986a), species identification (Stone et al., 1986b). and the running of a plant growth model (Lemmon, 1986).

The first and foremost opportunity for using expert systems technology in agriculture is with integrated crop management. Farmers, farm managers, extension specialists, county agents, Soil Conservation Service agents and others have to make high-risk decisions concerning management of their crops on irrigation, tillage, fertilization, pesticide applications and herbicide applications. Not only are the timings of these events important, but also the quantity or type are important. The USDA Agricultural Research Service, Crop Simulation Research Unit at Mississippi State, MS is currently developing a CrOp Management EXpert (COMEX) advisory system based on the dynamic cotton crop simulation model GOSSYM (Baker et al.,1983). This expert system will incorporate the knowledge of developers of the cotton model which predicts crop growth and yield in response to external weather variables, soil physical parameters, soil fertility, and pest damage and the practical knowledge of the extension specialists as production rules (also known as IF-THEN rules). Comax determines the strategy for irrigating, applying fertilizer, applying defoliants and cotton boll openers. For determining irrigation requirements, Comax uses three different types of hypothesized weather scenarios. It seems not enough factors have been considered. Actually, many factors should be considered for the very useful irrigation management.

Kumar et al (1989) developed a prototype expert system (ES) to determine the economic feasibility of a range of irrigation systems for a site specific situation. The ES uses information input by the user to determine possible irrigation alternatives and provide an economic evaluation of suitable systems based on domain-specific knowledge about soils, crops, irrigation costs and agricultural drought in Virginia. However, irrigation scheduling, the major irrigation management component, was not included in this system.

Halterman et al (1988) developed DBL-CROP, an ES. This system gives recommendations and advice for no-till double cropping wheat and soybeans in Indiana. Fundamentally, DBL-CROP can provide planting decisions and management suggestions. Irrigation scheduling is not dealt with in this expert system.

Broner et al (1990) implemented an intelligent optimizer for barley management which couples a crop growth model with the barley management rule base. This system gives advice on irrigation and fertilizer management and provides specific management scenarios which consider protein constraints. So the management strategy in this project can not be extended to other crops.

CALEX, a crop management expert decision support system, is being developed by Plant et al.(1987). This system is intended as a general purpose shell program for a variety of crops. It consists of two separate programs: an executive, written in C, and an expert system shell, written in Lisp. Initial development of the program was only focused on the development of a package of modules for California cotton. The CALEX/Cotton package presently includes agronomic management and pest management. In the agronomic management, fertilizer management is handled using soil and irrigation water test data if available. Regression equations are used to estimate the amount of nitrogen required, and the mode of application is determined from the soil type; Irrigation management is based on the water balance method. This package lacks sufficient consideration of diverse nutrients and irrigation methods to allow flexibility in practical use.

Balestrieri (1989) has developed an expert system prototype called FERTIL utilizing fuzzy logic for maize fertilization. It is an example of ESs for the determination of the optimal dose of nitrogenous, potassium, phosphorus fertilizer to hybrid maize cultures cultivated on family-run farms in North-eastern Italy (Veneto region). The knowledge base (particularly in relation to the rules for the determination of the dose and those of service) is relatively small, limiting it widespread applicability.

Evens et al (1990) have applied expert systems technology to develop a demonstration prototype of a Fertilizer Selection Advisor (FSA). The program represents an integration of conventional computing and expert systems technology, and is designed to provide expert recommendations enabling farmers to obtain the best return on their fertilizer investment. Initially, they only considered a single nutrient, nitrogen, as a factor for the development of FSA. They have not incorporated other nutrients (e.g., phosphorus, potassium, sulphur), additional economic and environmental factors (e.g., climate and weather patterns, fertilizer storage costs), and a greater variety of crops.

Although a number of expert systems for agricultural applications have been developed, an expert system which can deliver optimal advice on irrigation and fertilization for wheat hasn't been available. This study seeks to integrate the diverse knowledge on irrigation and fertilization management into a rule-based expert system.

3. THEORY, APPROACH AND DEVELOPMENT ENVIRONMENT

3.1 Theory

Artificial intelligence (AI) may be defined as "the branch of computer science that is concerned with the automation of intelligent behavior" (Luger and Stubblefield, 1989). Major topics of study in AI include robotics, natural language processing, machine vision, and expert systems(ESs). AI has achieved considerable success in the development of expert systems since the mid-1960s. In recent years, the field of AI has been recognized for its potential contributions to agriculture. Most of this attention has focused on the development and application of expert systems.

3.1.1 What are Expert Systems?

An **Expert System** (ES) is a computer program that relies on knowledge and reasoning to perform a difficult task usually undertaken only by a human expert (Parsaye et al., 1988). The area of ES development investigates methods and techniques for constructing man-machine systems with specialized problem-solving expertise (Hayes-Roth et al., 1983). Expertise consists of knowledge about a particular domain, understanding of domain problems, and skill at solving some of these problems. The principal power of an expert system is derived from the knowledge the system embodies rather than from search algorithms and specific reasoning methods (Parsaye et al., 1989). An expert system successfully deals with problems for which clear algorithmic solutions do not exist. Knowledge refers to information that has been procured from an expert. This knowledge can be roughly classified into two different categories: facts and heuristics. Facts are propositions that are known, either by observation or experience, to be true. Heuristics are subjective rules of good judgment ("rules of thumb") that characterize expert-level decision making in a particular field. Generally, heuristics are established through experience and cannot be learned from the standard theory presented in textbooks and classes. Heuristics enable the human expert to make educated guesses when necessary, to recognize promising approaches to problems, and to deal effectively with flawed or incomplete data. Elucidating and reproducing such knowledge is the central task in building ESs (Hayes-Roth et al., 1983).

3.1.2 Conventional Program versus ESs

ESs differ in important ways from both conventional data processing systems and systems developed in other branches of AI. In contrast to traditional data processing systems, AI applications generally involve several distinguishing features, which includes symbolic representation, symbolic inference, and heuristic search. ESs manipulate *knowledge* while conventional programs manipulate *data* (Waterman, 1986). Teknowledge, a company devoted to engineering commercial expert systems, characterizes the differences as shown in Table 1.

Table 1 Comparison of data processing and knowledge engineering

Data Processing	***Knowledge Engineering***
Representation and use of data	Representation and use of knowledge
Algorithmic	Heuristic
Repetitive process	Inferential process
Effective manipulation of large data bases	Effective manipulation of large knowledge base

ESs differ from the broad class of AI tasks in several respects. First, they perform difficult tasks at expert levels of performance. Second, they emphasize domain-specific problem-solving strategies over the more general "weak methods" of AI. Third, they employ self-knowledge to reason about their own inference processes and provide explanations or justifications for conclusions reached. And, last, they solve problems that generally fall into one of the following categories: interpretation, prediction, diagnosis, debugging, design, planning, monitoring, repair, instruction, and control. As a result of these distinctions, ESs represent an area of AI research that involves paradigms, tools, and system development strategies (Waterman, 1986).

The characteristics of an ES are totally different from those of a conventional program. Basic characteristics of an ES can be shown in Figure 1 (Waterman, 1986).

3.1.3 The structure of ESs

Figure 2 shows the basic structure of an expert system, which includes the user interface, a knowledge base, an inference engine and working memory (Miller, 1986). In additional to these fundamental components, many systems have an explanation facility and a knowledge base editor.

The user interface is an essential part of an expert system. Its task is to handle all the communication between the user and the expert system. The user interface allows users to query the system, supply information, receive advice, etc. Depending on user needs, the interface module may be designed using several different conventions, including menu-driven or graphical interfaces (Figure 3).

The knowledge base contains the domain-specific information used in problem solving. Generally, it is represented by facts, rules and frames (Figure 4).

Facts are pieces of information that can be used by expert system. The most common form of knowledge base is rule-based. Rules are a general way of representing information. Frames are a way of packaging knowledge within a well defined structure.

The part of an expert system that performs inference is called an inference engine. The task of the inference engine is to take the knowledge in

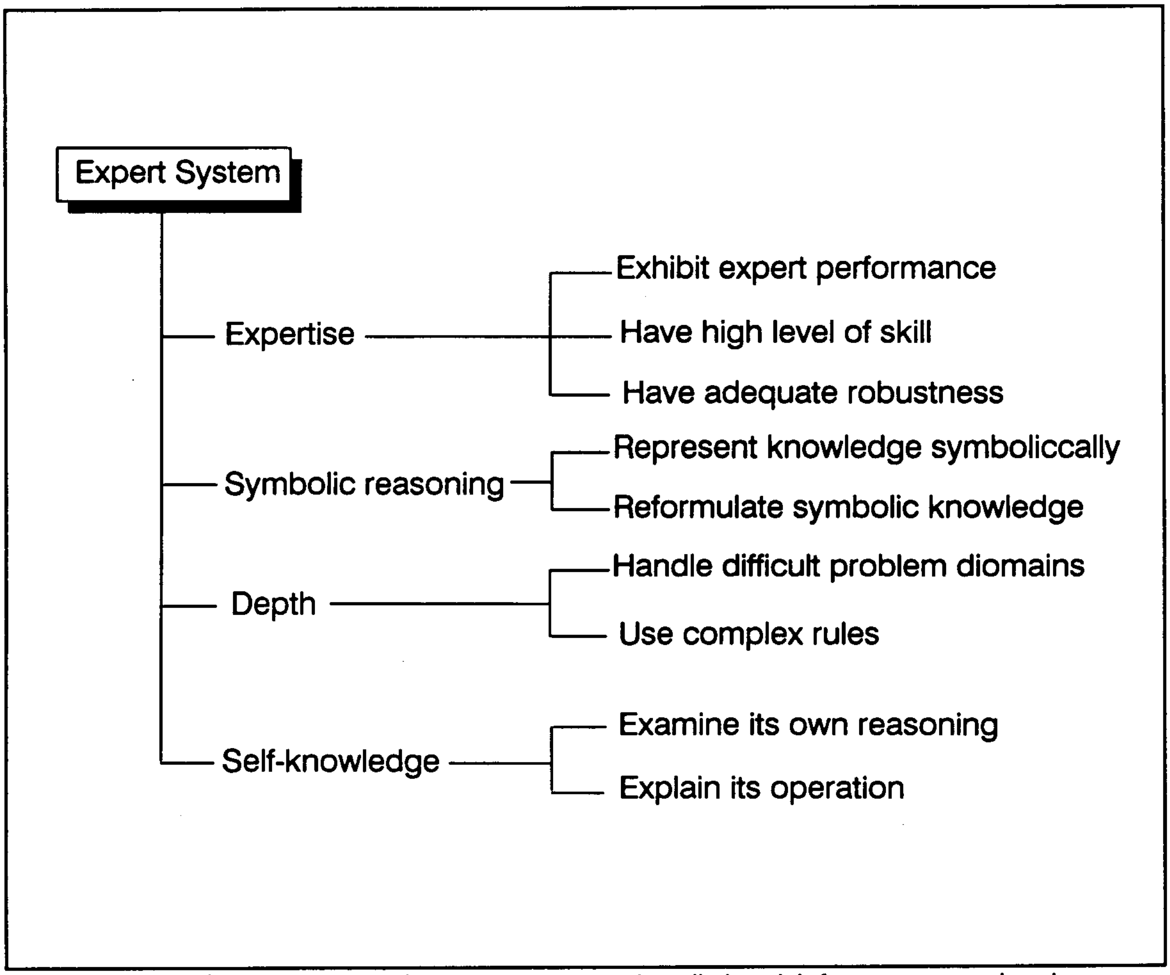

Figure 1 Characteristics of an expert system that distinguish from a conventional program

the knowledge base and carry out a set of actions that will utilize the knowledge in finding a solution to the problem. Two reasoning mechanisms are commonly used in rule-based inference engines, either alone or in combination (Figure 5). In forward (data-driven) inferencing (also called forward chaining), the system attempts to reason forward from the given facts to a solution. In backward (goal-driven) inferencing (also called backward chaining), the system works backward from a hypothetical solution (the goal) to find evidence supporting the solution. Often this requires formulation and testing of intermediate hypotheses (subgoals).

Working memory contains the case-specific data used by the inference engine while searching the knowledge base. Initially, working memory contains

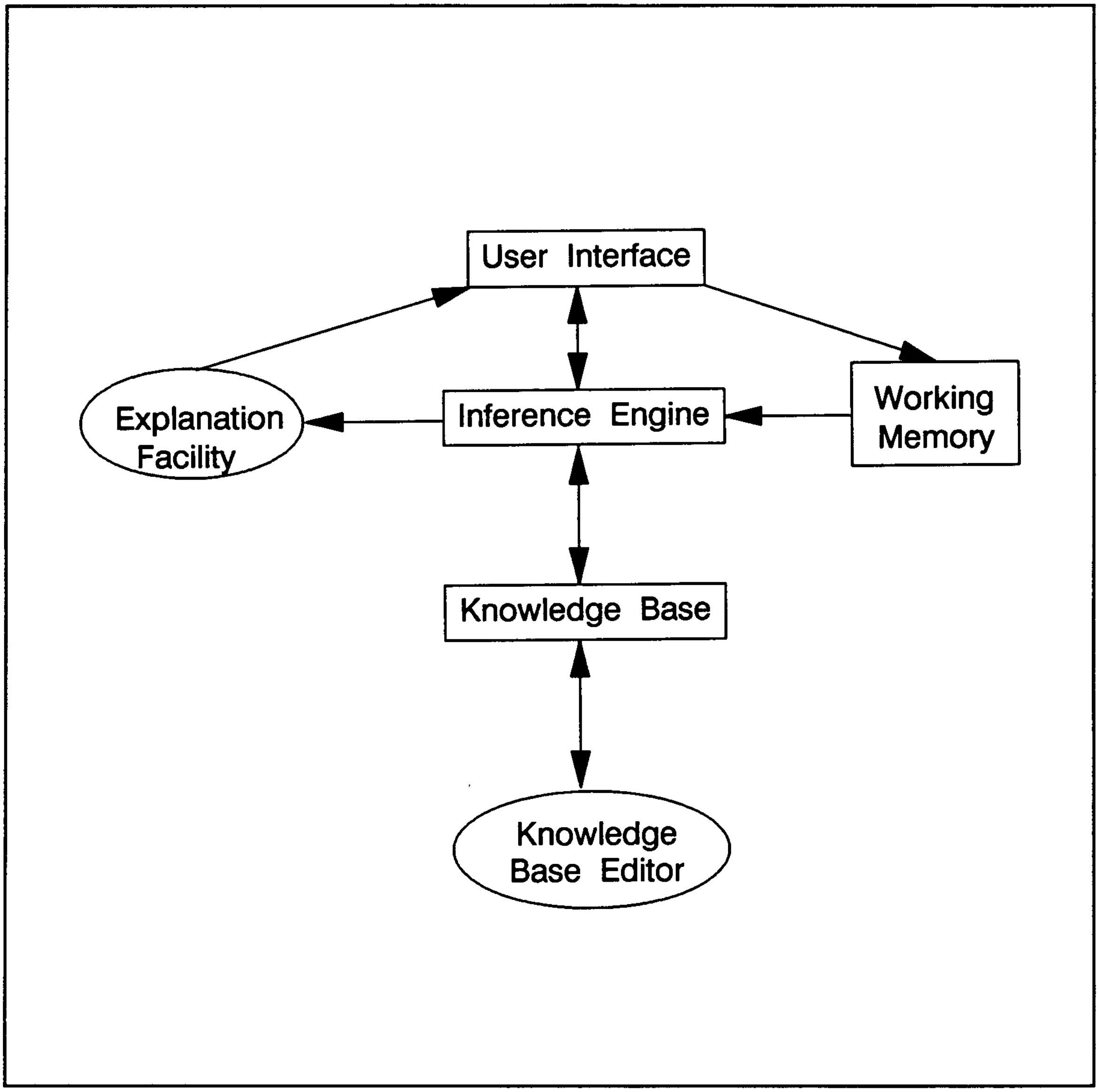

Figure 2 The basic structure of an ES

a set of assertions made by the user or retrieved from some other source such as a data base management system. During processing, additional data are added to working memory as inferences are made. Working memory is used to keep track of what is currently known about a problem for each stage of processing.

An expert system may also have a knowledge base editor - a tool used to access the knowledge base. Knowledge base editors are used by programmers to modify, extend and scan the knowledge base.

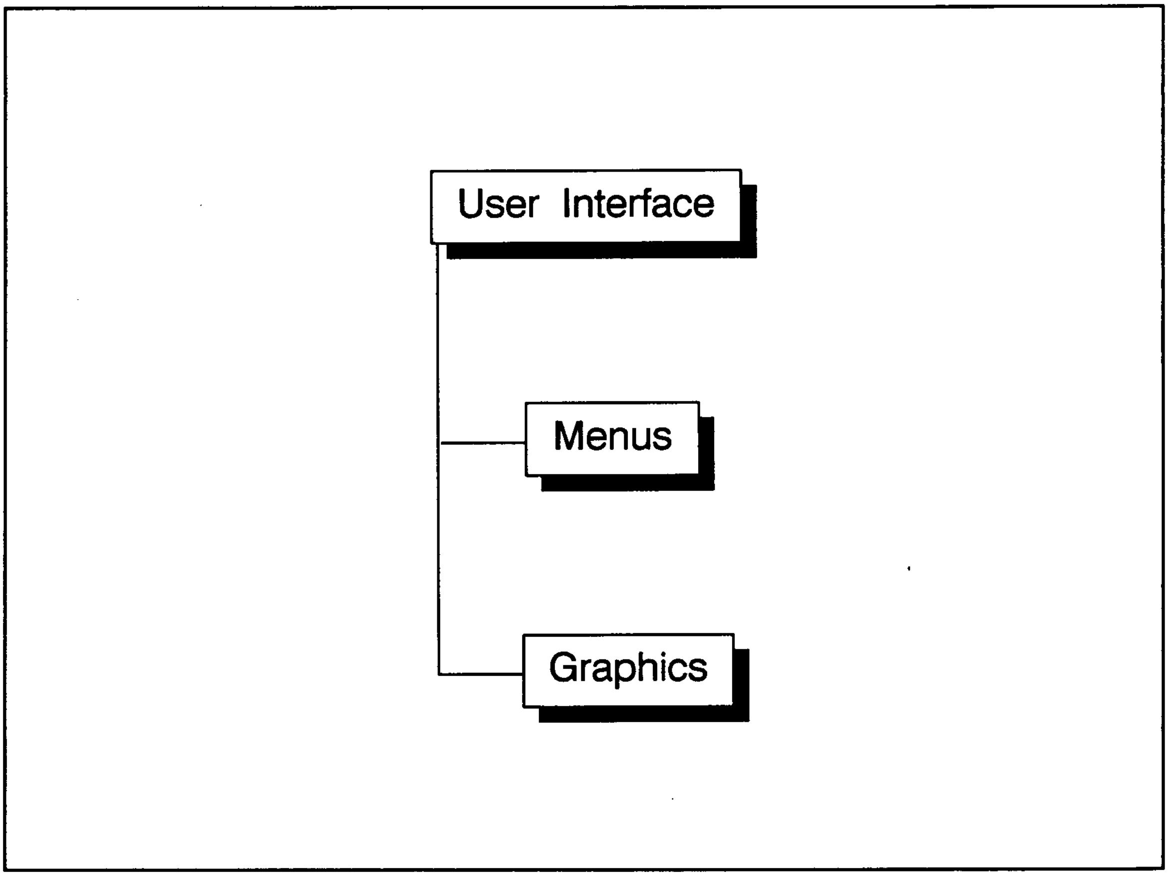

Figure 3 The types of the user interface

The practicality of an expert system, in many cases, is determined by the success of its explanation facility. The explanation facility not only satisfies a social need by helping an end-user feel more assured about the actions of the expert system but also serves a technical purpose by helping the developer follow the operation of the expert system.

3.1.4 Who Is Involved in ESs Building?

The primary players involved in expert system development are the *expert system*, the *domain expert*, the *knowledge engineer*, the *expert-system-building tool*, and the *user* (Waterman, 1986). The basic roles and their relationship to each other are summarized in Figure 6.

The ES is the collection of programs or computer software that solves

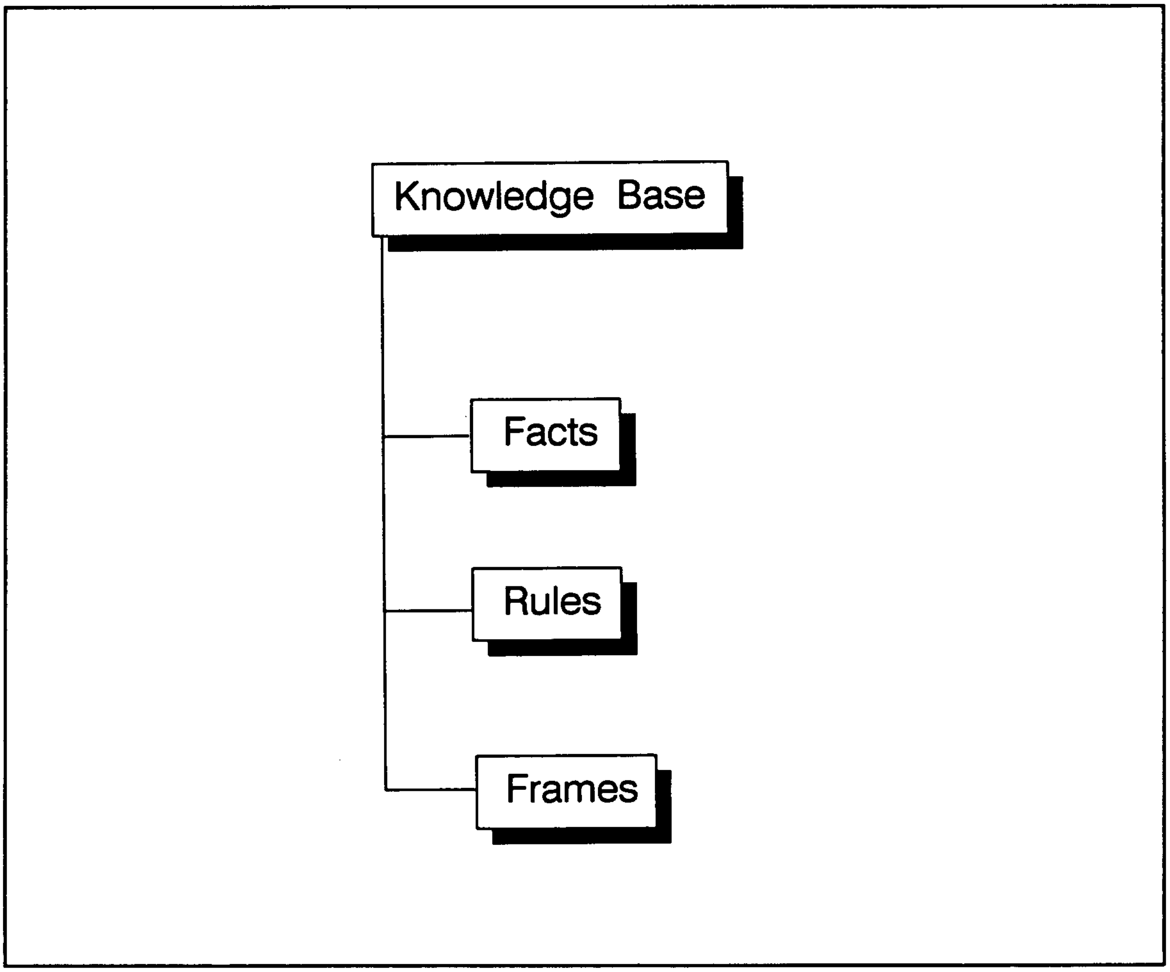

Figure 4 The components of the knowledge base

problems in the domain of interest. It's called a system rather than just a program because it contains both a problem-solving component and a support component. This *support environment* helps the user interact with the main program and may include sophisticated debugging aids to help the expert-system builder test and evaluate the program's code, friendly editing facilities to help the experts modify knowledge and data in the ES. and advanced graphic devices to help the user input and read information as the system is running.

The domain or area expert is an articulate, knowledgeable person with a reputation for producing good solutions to problems in a particular field. The expert uses tricks and shortcuts to make the search for a solution more efficient, and the ES models these problem-solving strategies.

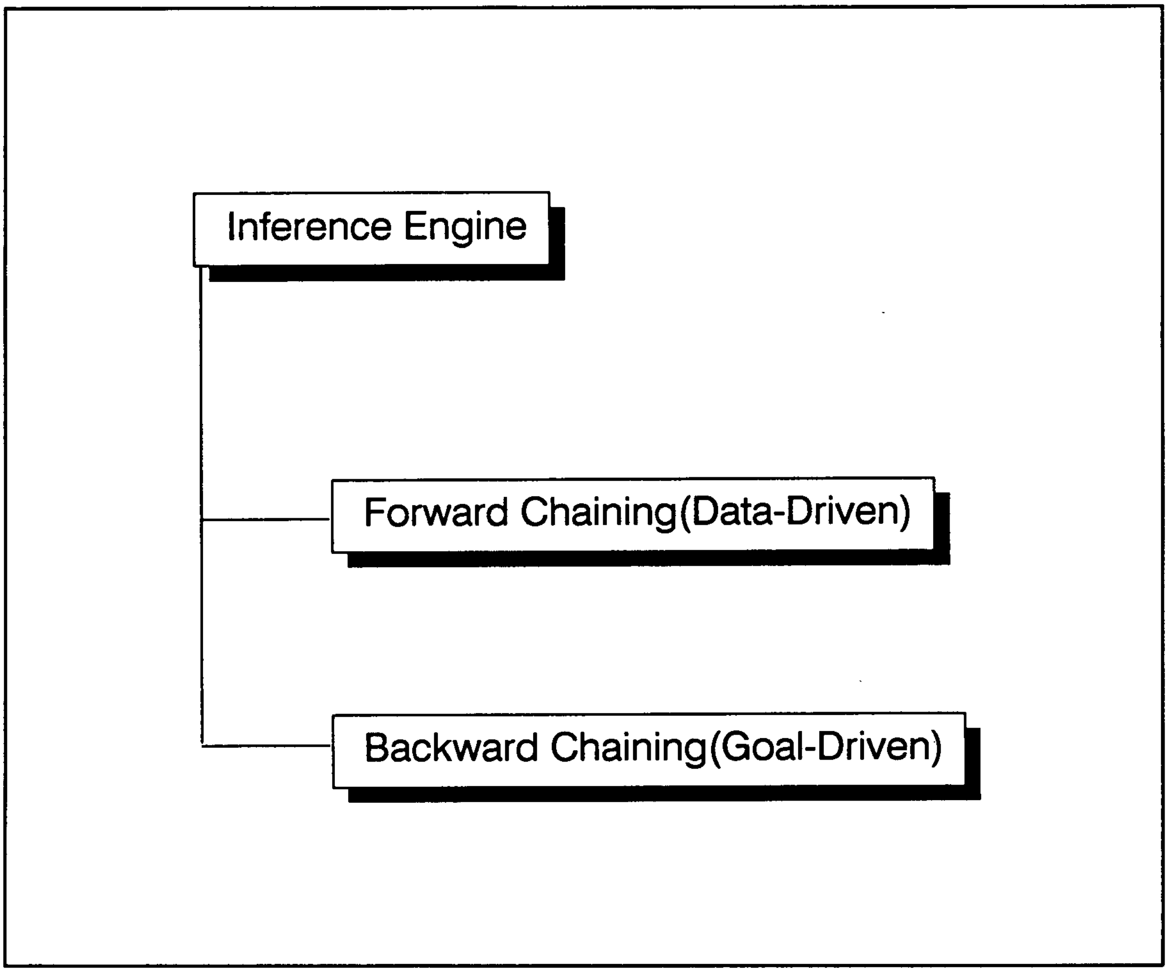

Figure 5 The categories of the inference engine

The knowledge engineer is a human, usually with a background in computer science and AI, who knows how to build ESs. The knowledge engineer interviews the experts, organizes the knowledge, decides how it should be represented in the ES, and may help programmers to write the code.

The expert-system-building tool is the programming language used by the knowledge engineer or programmer to build the ESs.

The user is the human who uses the ES once it is developed. The term *user* is a bit ambiguous. It normally refers to the *end-user*, the person for whom the ES was developed.

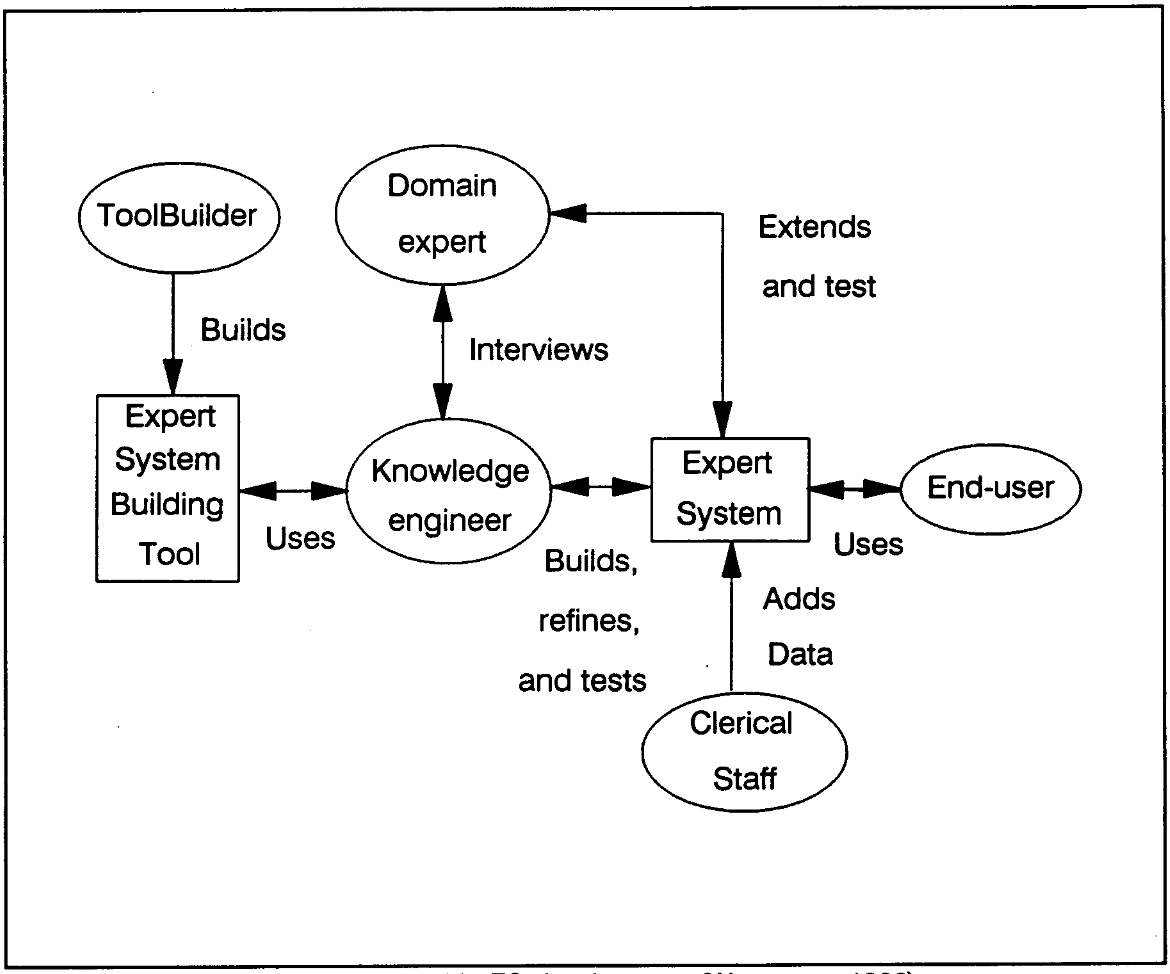

Figure 6 The players involved in ES development (Waterman, 1986)

3.1.5 What Have Expert Systems Been Used For?

We can broaden our understanding of ESs by reviewing some of their most characteristic uses. These will be described from two perspectives: the basic activities of ESs and the areas in which they solve problems.

ESs have been built to solve many different types of problems, but their basic activities can be grouped into the categories shown in Table 2.

Table 2 Generic categories of expert system applications (Hayes-Roth et al., 1983)

Category	**Problem Addressed**
Interpretation	Inferring situation descriptions from sensor data
Prediction	Inferring likely consequences of given situation
Diagnosis	Inferring system malfunctions from observables
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	Comparing observations to expected outcomes
Debugging	Prescribing remedies for malfunctions
Repair	Executing plants to administer prescribed remedies
Instruction	Diagnosing, debugging, and repairing student behavior
Control	Governing overall system behavior

Although the basic activities of ESs shown in Table 2 are easy to describe, it is misleading to use them to categorize existing ESs because many ESs perform more than just one activity. It is useful to categorize ESs by the types of problems they solve. Table 3. shows some of the problem domains in which ESs are now working.

Table 3 Application areas for expert systems (waterman, 1986)

Agriculture	Manufacturing
Chemistry	Mathematics
Computer Systems	Medicine
Electronics	Meteorology
Engineering	Military Science
Geology	Physics
Information Management	Process Control
Law	Space Technology

The most important terms discussed in this thesis are summarized in Appendix A.

3.2 Approach

The actual process of building an ES cannot be described in a single, straightforward algorithm (Evens,1989). The complexity of the construction process resists any formal definition, and hence ES developers cannot rely on a sequence of well-defined steps to guide them during development. Alternatively, ES developers have adopted an evolutionary method of construction, which at present appears to be the best approach.

No standard sequence of steps exists to describe the ES building process. Buchanan et al (1983) described a set of highly interdependent stages that roughly characterize the tasks involved. The phases are termed identification, conceptualization, formalization, implementation and testing, respectively (Figure 7).

The first phase, *identification*, involves characterizing all aspects of the

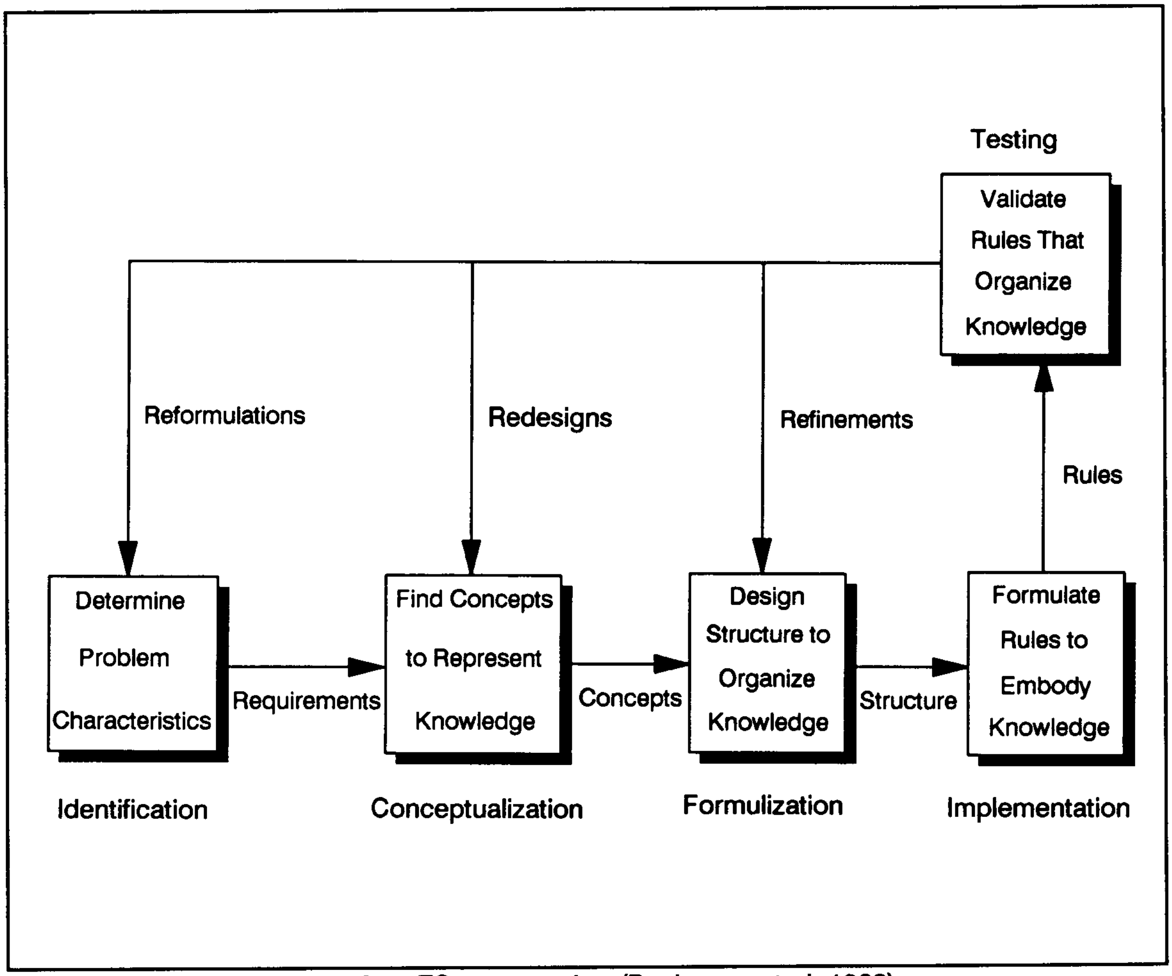

Figure 7 The stages of an ES construction (Buchanan et al, 1983)

problem. This includes defining the problem and its scope, identifying required resources and personnel, and establishing a set of realistic goals for the project. To define the problem, the knowledge engineer in cooperation with the domain expert attempts to identify, isolate and verbalize key problem concepts and their relationships. In essence, the knowledge engineer is trying to uncover the knowledge used to solve typical problems in the domain.

During *conceptualization*, the knowledge engineer and the domain expert work toward making the concepts and relations mentioned during identification more explicit. The knowledge engineer generally documents and diagrams information pertaining to the types of data available, relationships among objects in the domain, subtasks and strategies used to solve problems, and any constraints related to problem solving activities. At this point, an attempt to diagram a conceptual hierarchy of the domain space (or problem space) is usually undertaken. The domain expert's input is crucial to the success of this phase. It is his/her responsibility to verify that the knowledge engineer's conceptualization of the problem is correct before the next phase begins.

The next phase, *formalization*, involves expressing the key concepts, subproblems and relations in a more formal manner, as dictated by the knowledge engineer's choice of tools or framework. The knowledge engineer is concerned with selecting a representational framework that closely matches the characteristics of the problem at hand. Experience, informal experimentation with a preliminary prototype, collaboration with the expert, and knowledge about the available tools and languages can help the knowledge engineer select an appropriate tool. At the completion of this stage, a set of formal specifications describing how to represent the problem using the chosen tools or framework should exist.

During *implementation*, the formal specifications outlined in the previous stage are used as the basic for the construction of a prototype system. Programmers, under the guidance of the knowledge engineer, encode the data, knowledge and problem-solving methods uncovered in previous phases. The resulting prototype generally consists of data structures, inference rules and a control strategy for applying data to the inference rules. The form of the prototype is dependent on the particular representation language or tool used and many have to change during development.

Once a working prototype is produced, the next phase, *testing*, can begin. The utility and performance of the prototype are evaluated against sample problems prepared by the domain expert. Observing the prototype's behavior allows the domain expert to suggest possible modifications and extensions. Testing will generally uncover problems with the representational scheme, such as missing concepts and relations, knowledge represented at the wrong level of detail, or unwieldy control mechanisms (Waterman,1986). It is best to use sample problems that test the bounds of the system's knowledge, challenging the systems performance and uncovering any weaknesses. Problems uncovered during testing make it necessary for developers to recycle through the various phases of development.

3.3 Development Environment

The OSU|SHELL, an ES development environment, was used to develop the ESs framework for this project. OSU|SHELL was developed using the Arity/Prolog (Version 5.1) compiler by Dr. John Bolte, Bioresource Engineering Department, Oregon State University. OSU|SHELL is an expert system development and delivery system. It provides a backward-chaining inference engine and a windowing, menu driven user interface for rule-based expert systems. It provides a rule language and operates on knowledgebase files conforming to the rule language specifications. Additionally, knowledgebase editing and debugging facilities are integrated into the OSU|SHELL environment to facilitate rapid development of knowledgebases. OSU|SHELL is designed to run on any IBM/PC/XT/AT or 100% compatible computer. It requires at least 512K of RAM, with 640K being preferred. It can run off a floppy or hard disk, with hard disk preferred to speed program operation. Currently, the program runs under the MS-DOS or PC-DOS operating system, Version 2.0 or later.

4. PROCEDURE

The Crop Management eXpert (CMX), an ES designed to provide expert recommendations on the optimal irrigation and fertilization management, has been developed. To build the system, a development strategy, consisting of 1) identification - determining problem characteristics; 2) conceptualization - finding concepts to represent knowledge; 3) formalization - designing structures to organize knowledge; 4) implementation - formulating rules that embody knowledge; and 5) testing - validating rules that embody knowledge (Hayes-Roth et al. 1983) was used.

4.1 Identification

Identification, the first step for building an ES, involves characterizing the important aspects of the problem. The participants, resources, problem characteristics and project goals were identified. Each of these categories is now be discussed below in detail.

4.1.1 Participant Identification

Before the knowledge-acquisition process can begin, the participants must be selected and their roles defined. Dr. Marshall English and Dr. Walt Trimmer from the Bioresource Engineering Department at Oregon State University have been chosen as domain experts for CMX. They both have extensive experience and knowledge in irrigation management through their research and extension activities. During the knowledge acquisition process, these domain experts acted as informants who told the knowledge engineer about their knowledge or expertise. Additionally, the knowledge engineer in this study utilized textbooks and technical papers as other domain experts.

Dr. Neil Christensen from the Crop and Soil Science Department and Dr. Timothy Righetti from the Horticulture Department at Oregon State University, domain experts for CMX, have expertise in fertilization management. On the basis of their experience, fertilization management recommendations are provided.

The knowledge engineer in CMX is the author.

4.1.2 Problem Identification

Once the participants are chosen, the knowledge engineer and domain experts can proceed toward identification the problem under consideration. In order to generate the advice for the irrigation and fertilization management, it was determined that the following variables should be taken into account:

- irrigation strategies
- irrigation timing criteria
- crop growth stage
- soil moisture content
- field capacity
- adequacy criteria
- crop appearance
- soil types
- crop types
- value of the crop
- root systems
- actual Et rate
- growing season precipitation
- geographical area
- climatic conditions (humidity, temperature, wind, etc.)
- crop yield goals
- soil nutrient concentration
- grain protein requirement

- fertilizer types
- placement options
- toxicity constraints
- pests and diseases
- salinity
- irrigation and fertilization facilities

Each of the above variables can take on many alternatives and values. For instance, soil moisture content, Et rate and soil nutrient concentration may take on a variety of different values from one place to another and from one year to another. Two irrigation strategies can be used, 1) conventional irrigation and 2) deficit irrigation. Generally, making a deficit irrigation decision is more difficult than making a conventional irrigation decision. Crop growth stage and soil moisture content are two important factors for the decision making for the irrigation and fertilization management. Fertilizer is composed of nitrogen, phosphorus and potassium. Fertilizers can be applied in the following ways: banded before planting, banded with the seed, banded beside / under the seed, broadcast or topdressing. Because these variables can take on numerous values, making effective irrigation and fertilizer recommendations is difficult. In theory, to solve this problem, one could consider all potential recommendations by generating all possible combinations of the variables and selecting the most cost-effective alternatives. In fact, such an approach is not viable because the computational complexity of this problem has an exponential nature. on other hand, solving this problem involves judgmental, subjective logic. Experts in crop management do not use a formal algorithm for generating recommendations for irrigation and fertilizer management. Instead, they depend upon experience, intuition, and heuristic (thumb-rule) when making irrigation and fertilization decisions.

4.1.3 Resource Identification

Resources are needed for acquiring the knowledge, implementing the system, and testing it. Typical resources are knowledge sources, time, computing facilities, and money (Buchanan et al., 1983).

The domain expert and knowledge engineer must use various sources to obtain knowledge relevant to building the expert system. For the domain expert these include past problem solving experience, textbooks, and examples of problems and solutions. For the knowledge engineer the sources include experience on analogous problems and knowledge about methods, representations, and tools for building expert systems (Buchanan et al.,1983). During the construction of CMX, a variety of sources have been applied.

Time is a critical resource. It takes time for both the knowledge engineer and domain expert to get the first prototype running. For example, interviewing the domain expert, understanding important concepts and methods, and characterizing the problem take time.

Computing and financial resource are essential. For developing CMX, a computer facility and a number of software resources were always available to the knowledge engineer. Because the knowledge engineer is familiar with OSU ▌ Shell, an expert system development and delivery system. OSU ▌ Shell was used as the knowledge engineering tool to develop the knowledge base.

4.1.4 Goal Identification

Identifying the goals or objectives of building the ES is important. CMX was designed to play the role of expert and deliver advice on crop management to agents and farmers. The main goals of CMX focused on providing optimal recommendations on the irrigation and fertilization management.

4.2 Conceptualization

The main objective of CMX is to provide the advice on the optimizing irrigation and fertilization management. Some important concepts and relationships were discerned during the formulating of this sort of advice.

4.2.1 Irrigation Management

Irrigation management has changed dramatically since 1970. Numerous developments have occurred that impact irrigation management recommendation formulation.

Irrigation management consists of determining when to irrigate, the amount to apply at each irrigation and during each stage of plant growth, and the operation and maintenance of the irrigation system. The primary management objective is to manage the production system for profit without compromising the environment. The major management activity involves irrigation scheduling; i.e. determining when and how much water to apply. Successful irrigation depends upon understanding and utilizing irrigation scheduling principles to develop a management plan, and then efficiently implementing the plan. Scheduling provides information that managers can use to develop irrigation strategies for each field on the farm. Such strategies may be based on long-term data, representing average conditions, or may be developed as the season progresses, using real-time information and short-term predictions. In general, the irrigation strategy consists of traditional irrigation or deficit irrigation.

4.2.1.1 Irrigation strategies

The producer's management objective must be considered first when developing an irrigation scheduling strategy. The management strategy for an irrigated farm or region is normally dictated by economics. Irrigation is practiced when the benefits, however defined, exceed irrigation costs. These benefits include: increased and predictable yield; enhanced crop quality; and reduced farming risks. Where irrigation is included in crop production, the amount and manner of water application can significantly influence net returns. The principal economic variables include the price of irrigation water, the cost of applying the water, and the price received for the crop. The optimal level of applied water depends on the crop water production function which expresses the general relationships among the amount of applied water, the salinity level of the water, and crop yield. Simply, the relationship among the net return, the amount of water, and crop yield can be expressed by the following equation (McClendon et al., 1989):

$$R - Y * P - I * C$$

where:

R = return,

Y = the average yield, (t/ha),

P = the crop selling price, ($/t),

I = accumulated amount of irrigation applied, (cm), and

C = cost per cm of irrigation, ($/ha cm)

The available water supply and irrigation costs are usually the most critical factors in determining the appropriate management objective. Often irrigation water supply and irrigation costs are such that it is optimal to produce near maximum yields on the entire area that can be irrigated (land limiting case). In this case the entire area should be irrigated and the optimal depth of irrigation is usually about the same as that required to produce the maximum yield. Therefore, the appropriate irrigation scheduling strategy is to prevent crop water stress throughout the growing season. This has been the most common application of *traditional irrigation* scheduling, or *full irrigation* scheduling.

For other situations where the supply of water is inadequate to achieve maximum yield on the entire field, the area irrigated or the seasonal application depth, or both, must be reduced. The manager must also determine how to distribute the limited water supply throughout the season. Scheduling deficit irrigations within a season is an uncertain process due to varying climate and price conditions. Traditional irrigation scheduling practices are of little use for deficit irrigation.

Deficit Irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction. It is called by a variety of other names; partial irrigation, regulated deficit irrigation, ET deficit irrigation, limited irrigation, etc. (English et al., 1990). The fundamental goal of deficit irrigation is to increase water use efficiency, either by reducing irrigation adequacy or by eliminating the least productive irrigations.

Management of deficit irrigation is fundamentally different from conventional irrigation management. Rather than working to minimize crop water deficits, the irrigation manager must decide what level of deficit to allow and must recognize when that level has been reached. He may choose to allow deficits to occur at some times and not others, and he may also apply water at a lower level of adequacy in order to achieve the higher efficiencies and lower costs that are possible under deficit irrigation.

The potential benefits of deficit irrigation derive from three factors: reduced costs of production, greater irrigation water use efficiency and the opportunity costs of water.

Quantitative irrigation scheduling methods are based on two approaches: a) soil and/or crop monitoring, and b) soil water balance computations (Martin et al., 1990). For the monitoring methods, the soil water content or matric potential is generally measured at several places in the field to decide when to irrigate. Methods based on plant measurements generally involve monitoring leaf water potential or canopy temperature.

4.2.1.2 Irrigation Timing Criteria

Irrigation timing influences the yield, seasonal irrigation amount, and the storage efficiency of irrigation events that occur in-season (Martin et al., 1990). Excessive irrigation leaches salts from the root zone but may also carry pollutants to groundwater, receiving streams and other bodies of water. Under irrigation of determinate crops in the floral through pollination and early seed fill period may severely limit yields. Moderate stress in the early vegetative period may minimally affect yield of the reproductive organ. Translocation of assimilates from stems and leaves to the seed can partially abate stress effects in the late seed-fill period. Indeterminate crops may compensate for stress effects in early growth period by new floral and subsequent seed development at upper plant nodes. Crops harvested for forage usually reduce dry matter development during water stress and then resume near normal growth rates when stress is relived. Total seasonal dry matter is, however, reduced relative to the potential production.

Many methods for determining when to irrigate and the amount to apply have been developed and field tested. Some methods require instruments for sensing soil or plant water levels that indicate soil water deficits or plant water stress. Others use mathematical models for estimating periodic changes in soil water content. Inputs for these models usually involve current weather data and crop status information.

Irrigation timing methods/criteria often rely on the use of threshold values for a chosen parameter or indicator of irrigation need. Parameter thresholds for irrigation timing are usually are either soil or plant based. Selected threshold values may be varied with crop growth stage, the evaporative demand. water supply constraints, irrigation system capabilities, cultural practices, economic value of the crop, and weather forecasts (Martin et al., 1990).

4.2.1.2.1 Management Allowed Depletion (MAD)

Management allowed depletions are the most used criteria for irrigation timing, particularly for water balance methods of irrigation scheduling (Martin et al., 1990). These criteria express the proportion or percentage of the root zone "plant available or extractable" water storage capacity that can be depleted between irrigations for maintenance of a non-stress or low stress environment for crop growth. Usually, a depletion criterion of 50% which represents an average "safe" level for a wide array of crops and soils have been widely used. In order to make the irrigation decision using MAD, the following information should be considered:

- Crop and field identification
- Date of last irrigation
- Rainfall since last irrigation
- Estimated depletion of soil moisture
- Field capacity
- Optimum depletion (MAD)
- Estimated days before the next irrigation
- Approximate amount to apply
- General climatic forecast

If the above information is not available, some general information must be provided for the irrigation decision making.

- Crop growth stage
- Soil moisture level
- Crop appearance
- Soil texture

Given the above information, CMX can provide recommendations for irrigation scheduling.

4.2.1.2.2 Soil Water Potential

Soil water potential can be sensed during freeze-free periods with tensiometers. The tensiometer has a working range of 0 to -80 kPa. Tensiometers are most useful in soil textures where about 50% of more of the plant available water is within the tensiometer range. Taylor(1965) and Hagon and Stewart(1972) assembled extensive tables that give water potentials at which various crops should be irrigated. Approximate threshold soil water potentials are given for several crops in Table 4.

Table 4 Approximate threshold soil water potentials

Crop	Soil Texture	Soil Water Potential (kPa)	Reference
Alfalfa	Loamy sand	-50	Hanson (1967)
Alfalfa	Sandy loam	-80	Hanson (1967)
Alfalfa	Clay loam	-150	Hobbs et al. (1963)
Cotton	Clay loam	-150	Levin et al. (1964)
Cotton	Silt loam	-100	Brown et al. (1955)
Maize	Sandy loam	-80	Trimmer (1991)
Maize	Clay loam	-130	Garton et al. (1959)
Maize	Sand	-20	Stanberry et al(1963)
Maize	Silt loam	-75 to -200	Vittum et al. (1963)
Potato	Silt loam	-50	Trimmer (1991)
Potato	Loamy sand	-40	Trimmer (1991)
Potato	Clay loam	-60 to -80	Hobbs et al. (1963)
Potato	Sandy loam	-50	Fulton (1970)
Soybean	Sandy loam	-50	Whitt (1954)
Soybean	Silt loam	-150	Whitt (1954)
Wheat	Sandy loam	-80 to -90	Day et al. (1959)
Wheat	Clay loam	-140	Campbell et al.(1968)

Tensiometers require considerable time for preparation, installation, recording of observations, periodic servicing and removal from the field. Interpretations of the sensed matric potential may be confounded by poor soil contact, leaks and a limited tensiometer range.

4.2.1.2.3 Leaf Water Potential

Leaf water potential(Ψ_l) can be measured with commercially available pressure chambers. Extensive reviews of their use and associated procedures have been given by Ritchie and Hinckley(1975) and Turner(1988).

Plant leaf water potentials respond dynamically to prevailing evaporative demand. Near sunrise, Ψ_l normally rises(from the previous day's depression) to an overnight recovery level that is determined by the prevailing soil water potentials in the crop root zone. With rising evaporative demand, cell dehydration lowers Ψ_l. Typically, Ψ_l falls to its daily minimum in the midafternoon period and then rises toward recovery as evaporative demand declines with approaching sunset. The dehydration may induce partial to complete stomata closure when evaporative demand is high. The reduced stomatal aperture in these periods reduces transpirational loss and CO_2 influx, resulting in periods of stress-reduced photosynthetic activity.

The daily Ψ_l behavior suggests the use of threshold values for irrigation timing. Critical thresholds, however, may also be affected by prior stress history in the growing season, and in some species by significant increases in liquid flow resistances with growing season advance. Accompanying osmotic adjustments may cause stomata closing thresholds to decrease by several kpa from early to late season. Approximate threshold Ψl (daily minimum) values are given for several crops in Table 5.

Table 5 Approximate threshold leaf water potentials limiting transpiration, net photosynthesis and crop yield

Crop	Threshold Leaf Water Potential (MPa)	Reference
Alfalfa	-1.00 to -1.30	Aparicio-Tejo et al. (1980)
Cotton	-1.20 to -1.50	Ackerson et al. (1977b)
Maize	-1.20 to -1.30	Stegman et al. (1976) Barlow et al. (1977) Stegman et al. (1983)
Potato	-0.80 to -1.00	Stegman and Nelson (1973) Ackerson et al. (1977a)
Soybean	-1.10 to -1.50	Boyer (1970) Brady et al. (1975) Stegman (1989)
Wheat	-1.40 to -1.90	Millern and Denmead (1976)

Because time of day is an important consideration with this technique, measurements of leaf water potentials for irrigation timing are most suited to research applications. Applications of Ψ_l thresholds are most feasible if Ψ_l levels are estimable with physically based models that rely on readily available input data.

4.2.1.2.4 Water Stress Indices

Hand-held infrared radiometers are available to measure plant canopy temperatures. Canopy temperatures rise as water becomes limiting for transpiration. Idso et al.(1980, 1981a,b,c) developed empirical relationships for crop-air temperature difference in bright, mid-day sunshine with soil water levels sufficient to sustain energy limited transpiration rates. More physically based relationships describing an energy balance at the crop canopy show that crop-air temperature differences are influenced by the vapor pressure deficit of the air, the net radiation level, and aerodynamic and crop resistances (reviewed by

Jackson, 1982; Idso et al., 1986 and Jackson, 1988). Upper and lower limits(in bright sunshine) for crop-air temperature difference can be developed to quantify water stress. The upper limit$(T_c - T_a)_u$ represents the temperature difference occurring for severe stress when transpiration approaches zero (approximately 4-5° C; Hatfield, 1982; Jackson, 1982). The lower limit$(T_c - T_a)_l$ represents the temperature difference between the crop and the air when the crop is well watered. The lower limit has been found to depend on the vapor pressure deficit of the air. A crop water stress index (CWSI) has been defined by Isdo et al.(1980, 1981 a,b,c) as:

$$CWSI = \left[\frac{(T_c - T_a) - (T_c - T_a)_l}{(T_c - T_a)_u - (T_c - T_a)_l}\right]$$

CWSI varies from a value of zero for no water stress to a maximum value of one at severe stress.

Threshold CWSI values for irrigation timing are not well defined. Idso et al.(1981b) reported wheat yield reductions when mean CWSI during reproductive growth exceeded 0.2. Jackson(1982) suggested irrigation should be applied when the CWSI(for wheat) is in the range 0.3-0.5. Further research is needed to define optimal CWSI values for irrigation timing.

Jackson(1982) also demonstrated that CWSI can be defined as:

$$CWSI = 1 - \frac{E_t}{E_{tp}}$$

where:

E_t/E_{tp} = the ratio of actual to potential evapotranspiration rate.

This ratio (E_t/E_{tp}) ranges from 1 (ample water) to zero (no available water). Instantaneous values can be obtained from measurement or estimates of net radiation, crop-air temperature difference, vapor pressure deficit and aerodynamic resistance(Jackson, 1982,1988).

Hiler and Clark(1971) introduced a stress day index(SDI) concept for irrigation timing:

$$SDI = \sum_{i=1}^{n} (SD_i C_{si})$$

where SD is an indicator of the crop's water deficiency in growth stage i; and C_s represents the crop yield susceptibility in a given growth stage. Applications of this index for irrigation timing have been limited by the need to experimentally define or characterize the C_s vs.SD relationship.

Real Time Crop Growth Model Application

Crop growth models allow a greater integration of complexities in the soil-plant-atmosphere system that impact the decisions of timing and amount of irrigation, such as current and expected weather conditions, crop growth stage, the extent of root zone development, the soil water holding capacity, the ability of the soil to transmit water, the amount of water held at the beginning of the crop growth, and the soil fertility and salinity. Crop simulation models may facilitate the evaluation of irrigation management strategies on the basis of various decision criteria. However, the criteria that are used to select a particular irrigation strategy among various alternatives often depend to a large extent on the decision maker's attitude toward risk.

Real time application of crop growth models for irrigation scheduling is highly dependent on the availability of model inputs and a clear understanding by the user of the particular model's limitations. Models must be sufficiently well calibrated and validated for the intended application. Ideally, applications should also include sufficient data collection for real-time feedback and updating of sensitive model parameters.

Crop growth simulations for irrigation decisions may use the current season weather data prior to the decision date combined with several years of historical weather data for the rest of the season (Swaney et al., 1983). The user interacts with the model algorithms to update crop, soil, irrigation and economic information. Comparisons of expected net profit, water use, yield, energy use, etc. may be used as a basis for the decision options (a) irrigate today or (b) wait one or more days to re-evaluate the need to irrigate.

Because of their complexity, real time application of growth models may also require development of user friendly methods for data acquisition, model inputs, simulation runs and interpretation of data output.

4.2.2 Fertilization Management

The judicious use of fertilizer has a significant beneficial influence on plant growth. Sound usage of fertilizer increases crop yields and improves the quality of crops. Plant nutrition and soil fertility are, of course, key factors in production capacity and efficiency, if wise decisions are made for their management. Fertilization management mainly involves determining when to apply the fertilizer, how to apply the fertilizer and how much fertilizer to apply. The objective of fertilization management in CMX is to maximize net returns on fertilizer application. Net returns are determined by subtracting the total production costs (e.g., fertilizer costs, cultivation costs, pesticide costs) from the gross revenue procured from the sale of the harvested produce. Simply, a net return above variable fertilizer cost (R) can be calculated by the following equation:

$$R - Y * P - F * C$$

where:

R = return,

Y = average yield for field, (t/ha),

P = crop selling price, ($/t),

F = accumulated amount of fertilizer applied to field, (kg), and

C = cost per kg of fertilizer, $/ha kg

The task of determining the optimum yield — the yield that will provide the greatest margin of returns over fertilizer costs — is complex. Generally, yield is described as a function of nitrogen supply using crop modeling. The relationship between yield and fertilizer is probably quadratic. Fertilizer cost can be described as a linear function of the fertilizer supply. The optimal return can be determined by subtracting these two functions. The objective of the decision-making process is to construct a fertilization plan that produces the optimum yield. CMX is designed to provide important information about the fertilization management based on a predictions of crop fertilizer response. In order to make recommendations for the fertilization management, the following questions need to be addressed:

- What is the function of the nutrient?
- What are the elements of the nutrient?
- How to determine the nutrient requirement for a healthy crop?
- How to apply the fertilizer?
- What is the fertilization strategy?
- What are the constraints which relate to fertilization?
- How are the fertilization and the irrigation in the domain related?
- Should are recommendations made based on obtaining maximum yield, or maximum profit, environmental quality, a combination of all factors?
- How to make the decision for the fertilization based on the soil test?
- How to make the fertilizer decision from symptoms of the nutrient deficiency?

Like water, nutrients are important factors in crop production. The mineral nutrients in soil, along with carbon dioxide in the air, provide the raw building materials ultimately transformed and accumulated in the plant as dry matter. The greater the supply of building materials, the larger the plant at any given stage of development, up to its maximum genetic potential. Conversely, the larger the plant at any given stage of development, the greater the total supply of building materials needed for continued growth and development to full adult size. In other words, the larger the plant, the greater the demands of that plant for building materials if it is to get even bigger.

The major components of plant nutrition are nitrogen, phosphorus, and potassium.

4.2.2.1 Nitrogen

Plants need nitrogen for manufacturing proteins. Since proteins make up much of the internal contents of the cells, this element is typically needed in greater quantity than any other mineral nutrients (Cook et al., 1991)

Plants without enough nitrogen for continued growth and development become light green and then yellow; this symptom starts with the oldest leaves and progresses to the youngest leaves. Older leaves eventually turn brown and die while the limited nitrogen supplies are allocated by the plant to the newest growth.

In nitrogen management, it is critical to have a yield goal and a reasonable estimate of the number of heads and the size of the heads needed to reach that goal. A healthy wheat crop in North America generally needs about 2.4-2.7 pounds of nitrogen per acre (2.7-2.9 kg/ha) for every bushel of grain produced per acre (67 kg/ha).

In spite of the conveniences and advantages of applying nitrogen before planting wheat, it may be less efficient than applying fertilizer near or within the seed rows at planting, even in the drier wheat-growing areas. A more effective approach in fertilizer management for wheat health management may be to have the equipment and technology to apply fertilizers (nitrogen as well as other nutrients) at the time of planting (Cook et al., 1991). Banding at planting has several potential advantages over broadcast applications and, in some case, deep-band placement before planting. These include greater early seedling vigor from early root access, which may carry through to a higher yield; less chance of tie-up of the applied nutrients by surface residues or immobilization in soil; improved ability of the crop to compete with weeds, the crop having greater or more selective access to the fertilizer; and higher fertilizer-use efficiency.

The goal in wheat health management must be to maximize the capture of nitrogen within the plant, store soil nitrogen in plant residue for future crop production, and minimize nitrogen losses. Further, nitrogen must be available to the plant at critical times.

4.2.2.2 Phosphorus

Phosphorus is a component of the cell membranes and functions in the transfer and storage of energy within the plant cells (Cook et al., 1991). Like nitrogen, hydrogen, oxygen, and carbon, it makes up part of the structure of key molecules in plant cells, including DNA. It is also crucial to certain ongoing housekeeping functions and the integrity if existing plant cells. Without an adequate supply of this element, both the functions of existing cells and the generation of new cells are seriously impaired or prevented.

Plants without adequate phosphorus formal growth are stunted and poorly tailored, the stems are slender and poorly rooted, the leaves are smaller and darker green than normal, and plant maturity is delayed. One of the more diagnostic symptoms of the deficiency in some varieties is reddish or purple leaf sheaths. Good phosphorus nutrition can stimulate root formation and accelerate plant maturity.

Phosphorus exists in soil as phosphates with relatively low solubility in water and is therefore relatively immobile. The problem of phosphorus fixation in acid or alkaline soils can be minimized when fertilizing by concentrating the phosphorus in bands either before or at the time of planting. Banding below the seed at the time of planting has the added advantage of placing the fertilizer into immediate contact with the emerging radicle and seminal roots during seedling establishment.

The phosphorus needs of wheat are best met by fertilizing according to the results of a soil test. Phosphorus fertilizer should be applied when the available supply of the nutrient in the soil is low. Healthy wheat plants at maturity contain 0.3-0.5 pound of phosphorus for each bushel of grain produced (0.5-0.8 kg of phosphorus per 100 kg of grain). Thus, a crop producing 100 bushels per acre (6.7 t/ha) requires 30-50 pounds of available phosphorus per acre (35-55 kg/ha).

4.2.2.3 Potassium

Potassium is needed in the plant to help balance the positive and negative charges between the inside and the outside of the cell. It is also needed in the transport of photosynthates and the activation of certain enzyme systems, and it functions in the regulation of turgor pressure in the cells (Cook et al., 1991).

Adult wheat plants deficient in potassium tend to be short and have weak stems, owing to their short and spindly internodes.

Most soils in the Great Plains and the Pacific Northwest have adequate potassium for normal healthy growth of wheat. Potassium deficiencies are usually limited to sandy, highly leached soils where annual rainfall is well in excess of the annual evaporative demand.

A healthy wheat crop, by maturity, takes up 150-200 pounds of potassium for each 100 bushels of grain produced (25-35 kg/t). Like phosphorus, potassium fertilizer is generally most efficiently used by the crop when applied in bands, and crop responses to band applications are most common where conditions restrict root growth.

4.2.2.4 Toxicities

Toxicities from fertilization can occur in three different ways. In one, a given agronomic crop may respond negatively to an excess of a specific nutrient. In another, individual crops may be damaged by salt from fertilizers. Generally, this is due to improper fertilizer placement—fertilizers come in contact with the seed causing reduced germination. Finally, nutrient imbalances can by caused by overapplication of one nutrient. Generally, no more than 15-30 pounds of nitrogen per acre (depending on the formulation) can be placed safely with the seed in semiarid areas. Substantially higher rates are possible in high-precipitation area with a wet seed zone. Potassium fertilizer applied with the seed should be kept low, since it can also damage seeds and restrict seedling establishment. Once understood those factors are, we can make reasonable fertilizer recommendations.

The basic ideas for fertilizer recommendation are:

- Fertilizer recommendations should be made to assure that nutrients are not limiting yield. Thus, if in doubt, a nutrient is recommended.
- Fertilizer recommendations should include only those nutrients that can be expected to give a yield response, and at such a level so as not to cause significant loss of either N or P to the environment. This means that recommendations should be reduced for both K and P if they were to be lost by leaching or surface runoff. Maintenance treatments are not recommended if they are not likely to influence current yield.
- Fertilizer should be added to assure adequate amounts for the present crop and placed in a manner to give most efficient uptake of the fertilizer (i.e., band placement of some nutrients).
- Fertilizer should be added to bring the soil to a level determined to be adequate for crop growth and should affect prescribed ratios of the various soil cations to each other.
- Fertilizer recommendations should consider toxicities.

To arrive at a fertilizer recommendation CMX takes into consideration the yield goal, the soil type, the crop growth stage, soil tests results, soil moisture, fertilizer, toxicity, and residue from the previous crop.

4.3 Formalization

The formalization process involves mapping the key concepts, sub-problems, and information flow characteristics isolated during conceptualization into more formal representation based on knowledge-engineering tools (Buchanan et al.,1983). The primary goal of CMX is to arrive at solutions through this process. OSU▌ Shell, an expert-system-building tool, has been used to represent the concepts and ideas derived from the conceptualization stage. OSU▌ Shell is a suitable tool for building the preliminary prototype.

In AI terms, the irrigation and fertilization management is best characterized as a planning problem with constraints. Based on these constraints, CMX can generate a variety of recommendations for optimal irrigation and fertilization management.

4.3.1 Irrigation

The critical issue of the irrigation management, irrigation scheduling, involves generating a plan that explains when to apply water and how much to apply. When setting up this plan, numerous constraints need to be taken into account, including the crop growth stage, the field capacity, the allowable depletion, the irrigation facilities, the optimal water stress index for the specific crop, the optimal soil water potential for the particular crop and soil, and the optimal leaf water potential for the specific crop. The goal of CMX for irrigation scheduling is to develop effective plans while complying with these constraints. For example, if using MAD irrigation timing index, CMX can obtain a diversity of plans in determining when to apply water and how much water to apply in terms of different constraints such as soil types, field capacities, and crop growth stages. Irrigation decisions are derived from the following knowledge representation using an irrigation time criteria — MAD (Table 6).

Table 6 A formal representation of concepts using an irrigation time criteria - MAD

Assert the crop type.
Assert the soil type.
Assert the cumulative soil moisture depletion to the current day.
Assert the total effective rainfall since the last irrigation.
Assert the actual evapotranspiration rate since the last irrigation.
Assert the total days since the last irrigation.
Assert the crop growth stage.
Assert the allowable depletion.
Assert the field capacity.
Assert the average evapotranspiration rate for the three preceding days and three forecast days.
Assert whether the moisture depletion is greater than the allowable depletion.

Similarly, the irrigation decisions can be formed from the following table (Table 7) by using the general information.

Table 7 A formal representation of concepts from general information

Assert the crop growth stage.
Assert the current soil moisture level.
Assert the current crop appearance.
Assert the soil texture

4.3.2 Fertilization

The key question of the fertilization management involves providing a plan to apply the fertilizer, how to apply the fertilizer, in what amounts to apply the fertilizer, and what specific fertilizer compounds to apply. When establishing this plan, numerous constraints need to be considered, such as the geographical area, the crop growth stage, the toxicity limits of fertilizer compounds, the water deficit, and the fertilizer placement. The goal of CMX for the fertilization management is to obtain an efficient plan while abiding by these constraints. In order to make fertilizer decisions, CMX requires knowledge of available actions, anticipated consequences of actions, and alternative courses of action. In the CMX prototype, knowledge is represented using facts and rules. During the knowledge representation, various procedures have been used to assert the behavior of objects. For example, we compare the total nutrient requirement with the current soil nutrient concentration and decide whether or not to apply a certain fertilizer. During the formalization stage, the key concepts and their relations are characterized into a formal representation. For instance, through the analysis of a soil test a representation which is usable within the development environment is shown in Table 8.

If no soil test data are available, general information such as symptoms of nutrient deficiency is used to generate the fertilization strategies for the farmers.

Based on the information gathered at this stage, the knowledge base is built using production rules. CMX provides a capability for integrating gathered information to generate recommendations in a powerful and versatile framework by Encoding knowledge as relative easily understood facts and rules,.

A typical rule used in CMX is shown in Figure 8.

Table 8 A formal representation of concepts using soil test data

Assert the crop type.
Assert what best describes your geographical area.
Assert the crop yield goal.
Assert which nutrient you want to deal with.
Assert the total nutrient requirement.
Assert the crop growth stage.
Assert how to apply the fertilizer.
Assert whether the soil moisture depletion is greater than the optimal depletion or not.
Assert the soil nutrient concentration
Assert the high protein requirement for the specific crop.

RULE	decision for nitrogen at planting
IF	crop growth stage is at planting
AND	soil nitrogen concentration is current soil nitrogen concentration
AND	placement option is banded with seed
AND	soil moisture depletion is greater than the allowable depletion
AND	soil nitrogen concentration is less than minimum nitrogen requirement
AND	geographical area is semiarid area
THEN	First, you need to irrigate to relieve water stress (please refer to irrigation scheduling). Then, you may apply nitrogen at planting. Generally, no more than 15 - 30 pounds of nitrogen per acre (depending on the formulation) can be placed safely with the seed in semiarid area.

Figure 8 One of the rules for fertilizer management

4.4 Implementation

The goal of the implementation phase is to turn the concepts and relations between them into a working computer program. During this stage, we first need to design the system and select the proper building tool. Second, we need to define a particular control and information flow to let the knowledge representation become an executable program. Finally, we develop a prototype expert system. The CMX prototype consists of three main components: 1) a knowledge base, containing the factual and relational knowledge about the irrigation and fertilization management; 2) an inference engine, providing the reasoning capabilities and control strategy to formulate recommendations; and 3) a user interface to provide friendly user interaction with the system (Figure 9).

4.4.1 System Design

CMX was designed to provide advice for optimal irrigation and fertilization management. In order to accomplish this, the system must include all the practical concerns that an expert would be likely to address. It must also be able to deliver advice to users in a way that they are accustomed to receiving it from human experts. The overall design of the system consists of two subsystems: 1) irrigation management; and 2) fertilization management (Figure 10). The goal of the system is to deliver consistent recommendations over the course of a growing season. Irrigation management and fertilization management are drawn from many different disciplines and from sub-fields within those disciplines. To reflect this, the system is designed as two separate knowledge structures, each dealing with its own portion of the growing season.

This design helps make it possible to organize, deliver and maintain a system that deals with a large number of irrigation and fertilization issues over a significant period of time. In order to retain its coherence and relatively small

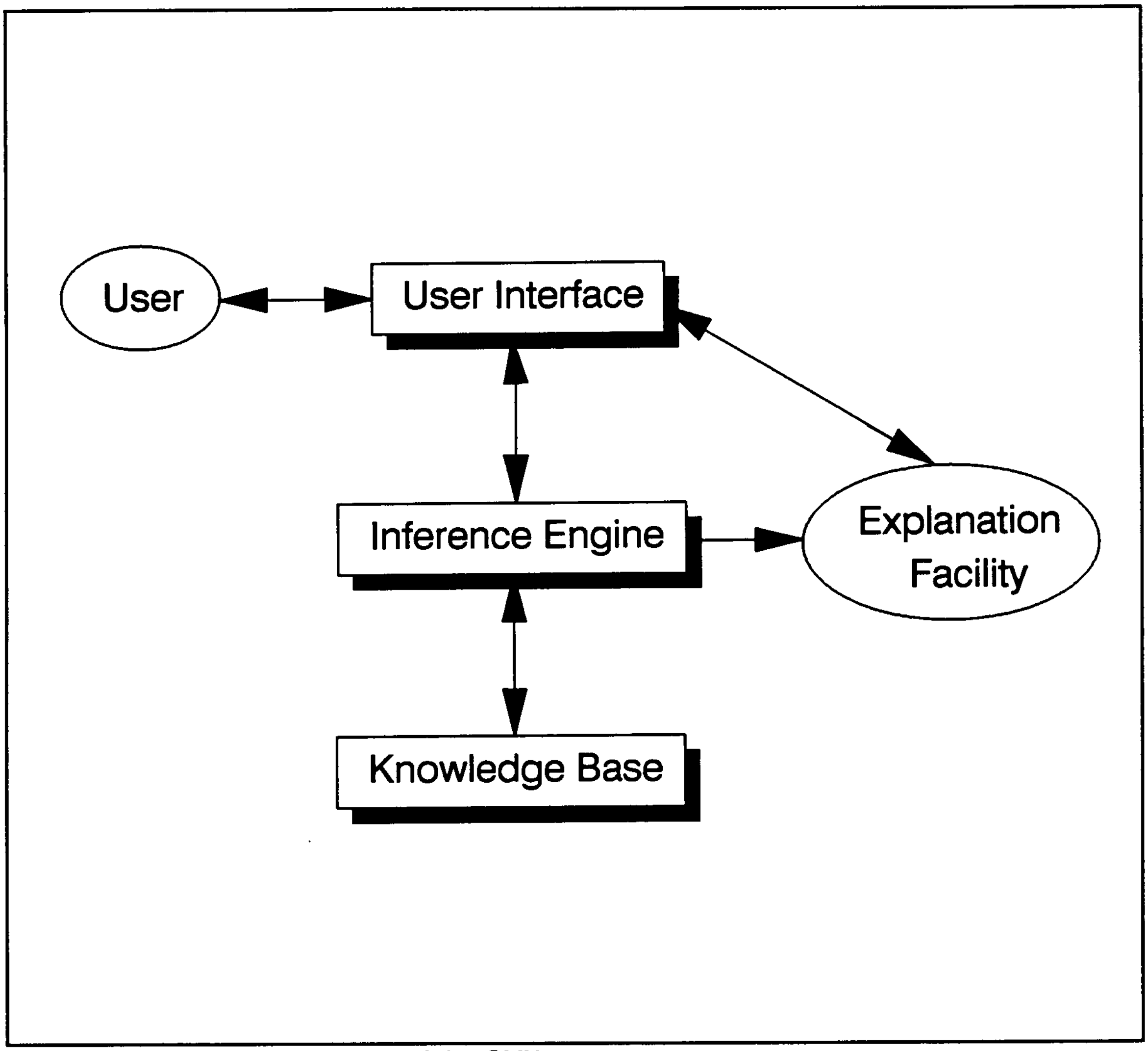

Figure 9 The components of the CMX

size, the system is designed to operate in deterministic fashion. The system controls all questions that will be asked in the course of a session; the user may only answer these questions. In some cases, the user is given options that offer him some small amount of freedom in viewing alternate input data and considering alternate paths of reasoning and action. Also, the user is free to read an explanation which gives much more detail about a particular issue. The user can access irrigation scheduling and fertilizer management.

Next we designed how to represent the knowledge so it can be

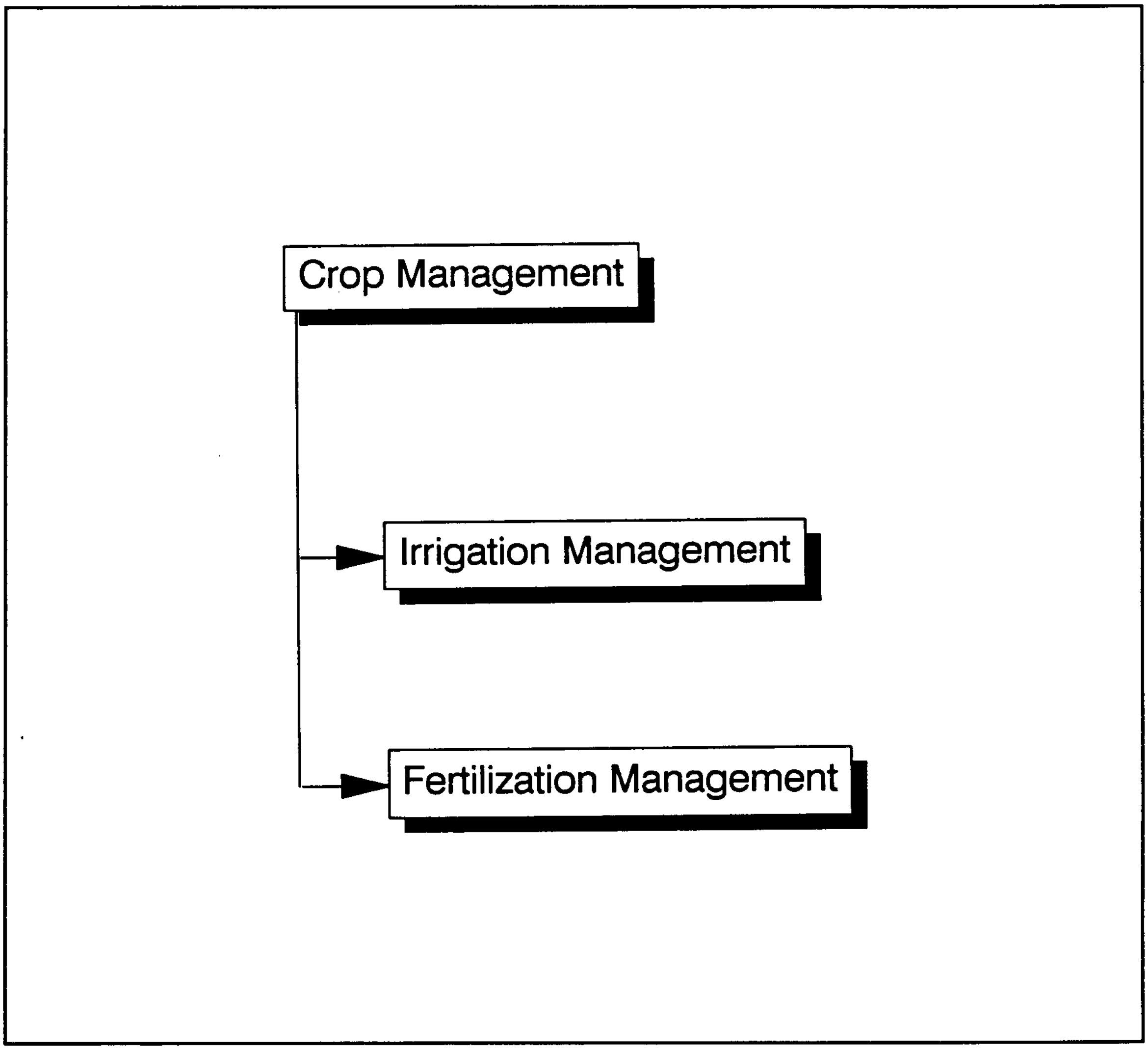

Figure 10 The components of the crop management

recognized by the patterns of inference. One of the most frequently used methods of representing knowledge is through a construct known as a production rule ('if-then' rule). Most systems to date have been rule based, with their knowledge encoded as a series of if/then statements describing conditional relationships about the domain. The antecedent (the 'if' part) of a production rule is composed of conditions which may or may not be true. If all the conditions listed in a rule are true, then the hypothesis (the 'then' part) is true and any actions associated with that rule are carried out. Knowledge in the CMX is represented by using a production rule. An example of an if-then rule in irrigation management might be: if crop growth stage is mid and if soil moisture is wet, then no irrigation is needed. Production rules allow the system the flexibility to deal with all the practical concerns that an expert would be likely to address. They also help to facilitate the other necessary component of a practical system, the ability to deliver advice to the grower in a way that he is used to receiving it from a human expert. Rule-based systems have several advantages over conventional approaches for encapsulating knowledge. These advantages include: 1) capability for manipulation of both symbolic and numeric information; 2) separation of knowledge (in the knowledge base) and control (in the inference engine), allowing easier encoding and maintenance of the knowledge in the system; 3) use of "natural language-like" syntax in specifying the rule structure, logic and content, allowing rapid prototyping and system development; and 4) capability for handling uncertain information and explaining system behavior.

As a result, the users have access to the opinion of experts, and knowledge within this field of study is gathered, and organized in a concrete expression for the practical application of that knowledge in the real world. The scope of these benefits would be markedly increased if the system were expanded to include pest management.

A number of user-friendly expert system shells have been developed around the rule-based paradigm, greatly facilitating implementation of these systems.

4.4.2 Building Tool Selection

In order for the knowledge to be represented in program environment, we need to select whatever building tools are available for the chosen representation. New development tools have emerged at an astonishing rate over the past few years. The emergence of expert system shells has speeded up the development of an expert system. Shells can be narrow, application-oriented tools or broader more general-purpose tools. Because of the wide range of expert system shells available, it is necessary to select the best development shell for a given application. A shell is a software module designed to promote the development of knowledge-based systems, much the same as spreadsheets promote rapid development of accounting and business decision-support systems (Engel et al., 1991). A set of clear guidelines for the selection of a category of expert system development shells for given expert system task domain does not exist. However, a few people give the approach to shell selection. A key reason for prototyping is to determine if the shell selected will work properly for the application (Richer,1986). Waterman (1986) and Hayes-Roth et al. (1983) suggest that in matching a shell to a problem, one should consider characteristics of the problem domain, characteristics of the likely approach to solving the problem, and the desired characteristics of the expert system.

The OSU Shell, an expert system development and delivery system, was used. This shell provides a backward-chaining inference engine and a windowing, menu driven user interface for rule-based expert systems.

4.4.3 Knowledge Representation

As long as the knowledge in this framework is made consistent and compatible and organized to define a particular control and information flow, it becomes an executable program. Because irrigation and fertilization management issues cover a great deal of information, we must make it explicit to specify the contents of the data structure and the control strategies. After that, the knowledge can be incorporated into executable rule-based system. Eventually, CMX gives the user access to expert recommendations in the matter of irrigation and fertilization management.

4.4.3.1 Irrigation

As we mentioned above, irrigation management consists two components: 1) irrigation scheduling; and 2) irrigation system maintenance.

Because irrigation scheduling is the major event in the irrigation management, CMX is currently only concerned about irrigation scheduling. During the process of irrigation scheduling, we also need to consider the irrigation strategies, e.g., conventional (full) irrigation and deficit irrigation. For each strategy, CMX may apply some different methods. Based on the specific data, CMX can use a variety of methods to make the irrigation decisions for the particular strategy. For instance, if there are specific data available, CMX can use irrigation timing criteria to give the optimal irrigation advice to the users. Otherwise, CMX may use general information in the current field to deliver expert opinions to the users. An information flow diagram is given in Figure 11, 12, 13.

The rule base encodes knowledge structures about irrigation management, irrigation strategy and irrigation timing criteria. The inference engine insures that only the relevant portion of that knowledge will be accessed in the course of a consultation. An example of the kind of considerations that compose a rule and allow the system to arrive at a recommendation is shown in Figure 14. The first block of statements (the 'if' part) are conditions which may or may not be true. If all the conditions listed in a rule are true, then the hypothesis (the 'then' part) is true. The rule-base, when processed by the OSU▌ Shell inference engine, then will make queries of the user through a customized user-interface, evaluate rules to establish conclusions. A lot of alternatives have been generated through the layout of the knowledge structure.

During the consultation, CMX allows the user to either provide data or make choices. CMX uses OSU▌ Shell rule language keywords to fulfil this task. For example, CMX may list choices and lets the user choose the possible soil type.

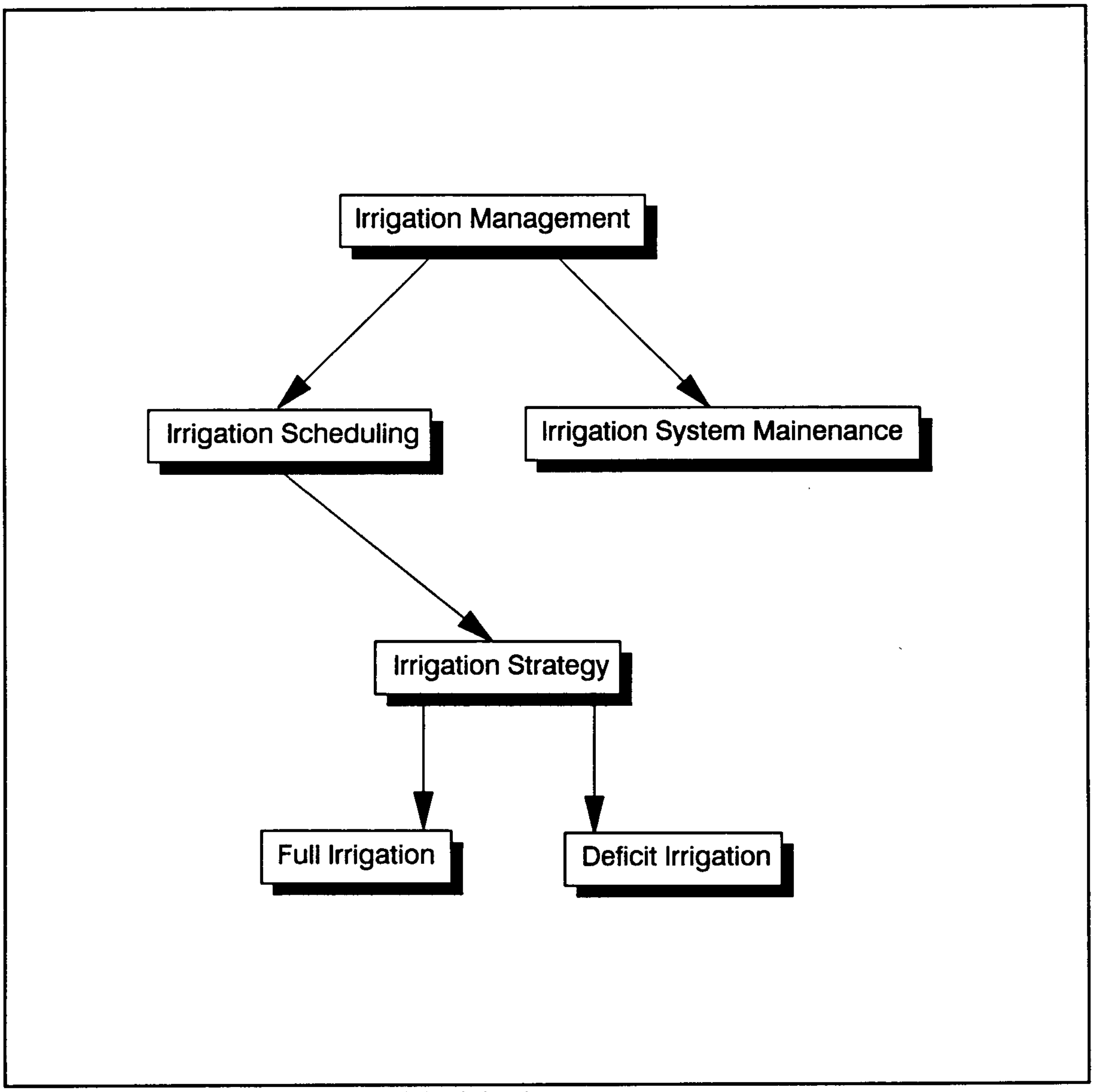

Figure 11 The components of the irrigation management

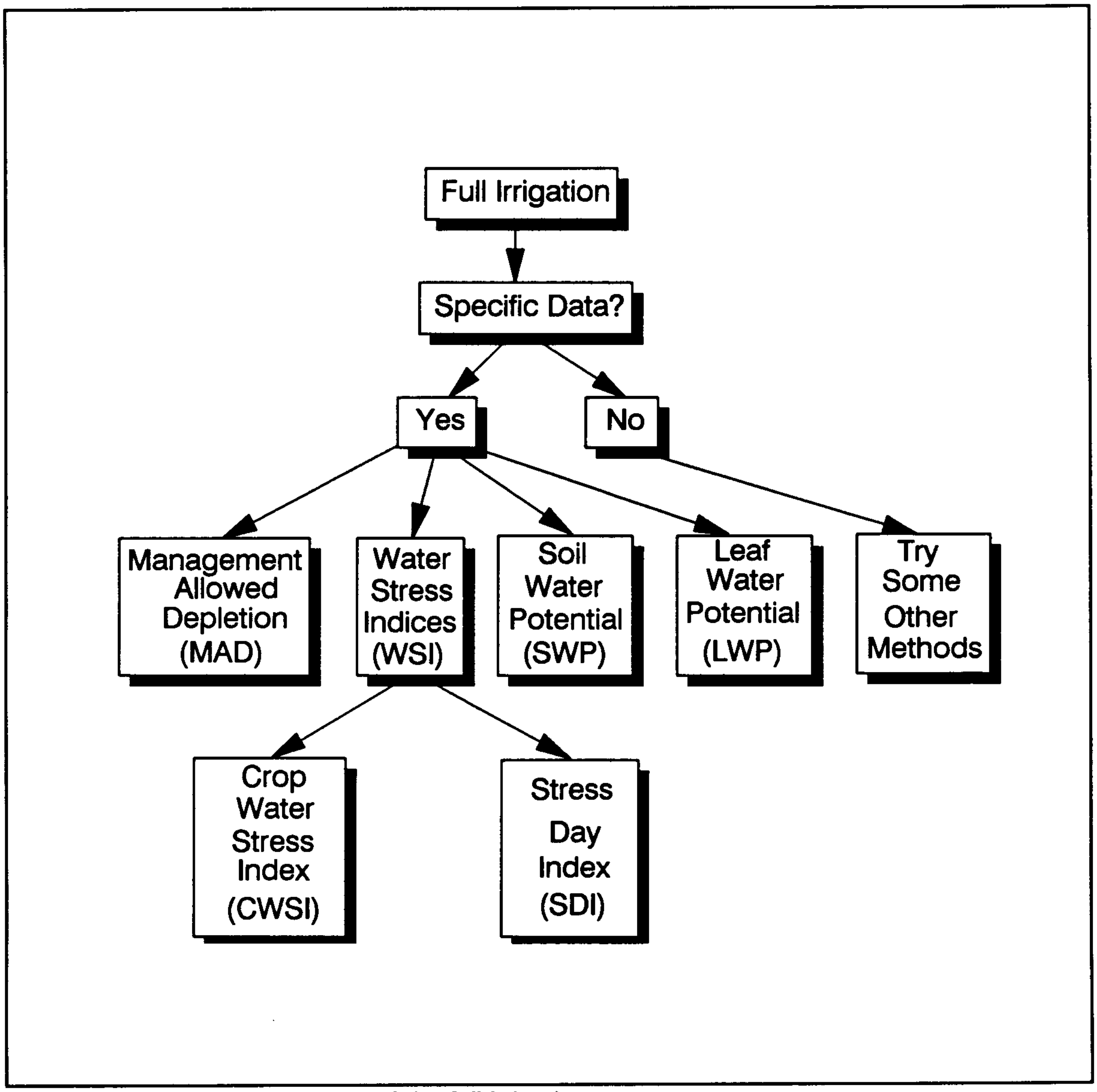

Figure 12 Information flow of the full irrigation

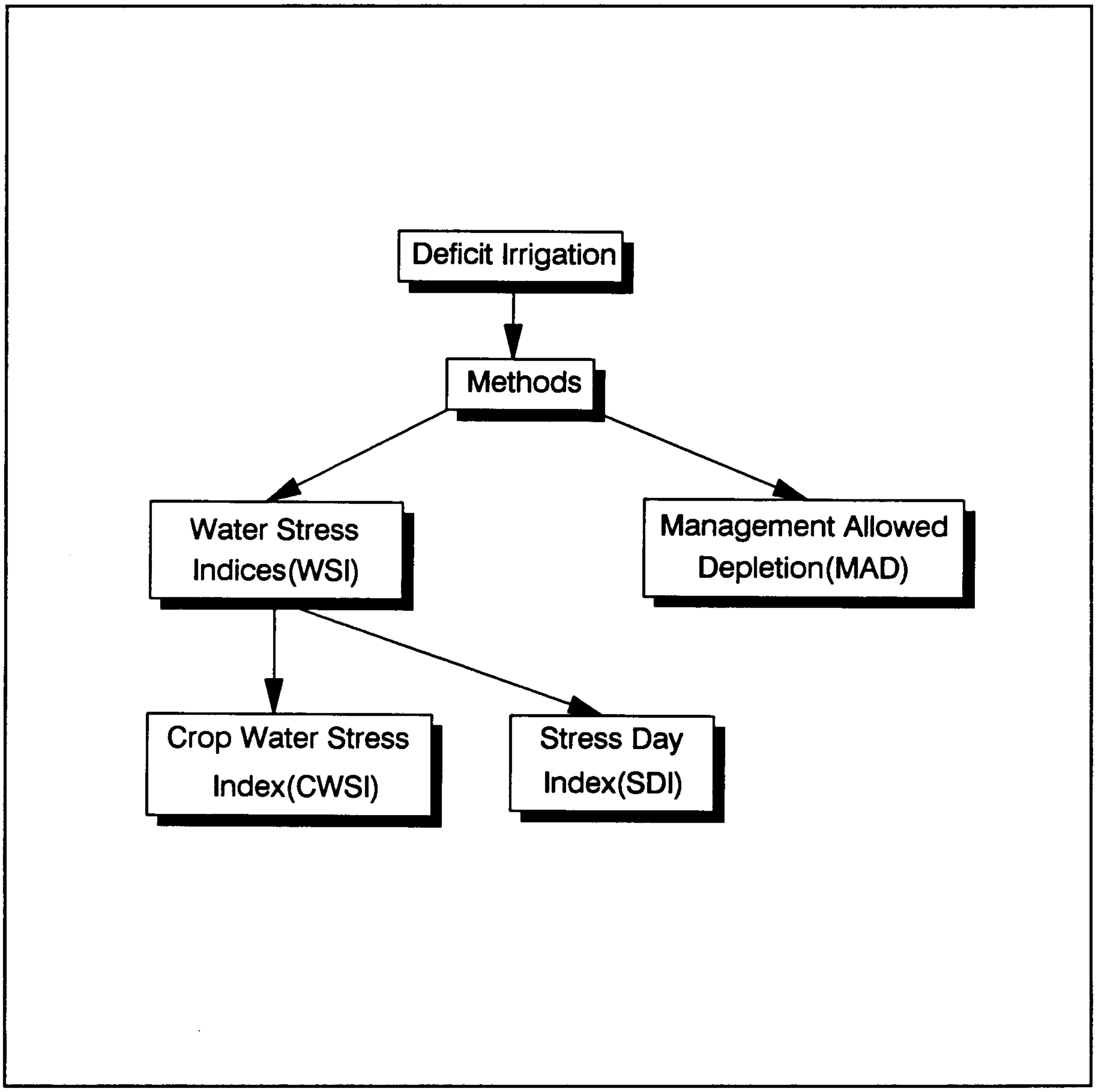

Figure 13 Information flow of the deficit irrigation

rule	determining full irrigation using MAD
If	you are dealing with irrigation scheduling
and	irrigation strategy is full irrigation
and	irrigation timing criterion that you want to use is Management Allowed Depletion
then	recommendation--Now you are using MAD method to make full irrigation decision.

Figure 14 An example rule from CMX

Applying the irrigation timing criteria and other methods, CMX provides recommendations for the irrigation scheduling. For example, using SWP and LWP criteria, CMX delivers the advice for the different crop types and soil textures. The analysis of these structure is shown in Figure 15 and 16.

A typical rule from above knowledge representation is shown in Figure 17. In the example given, a condition that deals with full irrigation using timing criteria is in turn dependent on other condition sets, ones which are made of irrigation strategy, and irrigation methods which the users prefer to apply.

Figure 18 shows a schematic layout of the knowledge structure using CWSI. Because threshold CWSI values for irrigation timing are not well defined, we can not derive a lot of rules using the CWSI criteria. Jackson (1982) suggested irrigations should be applied when the CWSI (for wheat) is in the range 0.3-0.5. Further research is needed to define optimal CWSI values for irrigation timing.

Because so much information is needed to arrive at clear and precise solutions it is difficult to organize and build the structure of knowledge. For example, CMX needs to take several major steps when it tries to transfer the irrigation decisions to the users by using MAD criteria. First, CMX needs to estimate the cumulative soil moisture depletion to the current day. Second, CMX needs to determine whether users should irrigate or not, by comparing the cumulative soil moisture depletion with the allowable depletion. Finally, CMX tells users when to irrigate and how much to irrigate. The information flow using MAD is shown in Figure 19, 20, and 21.

When CMX uses MAD to make the irrigation decisions, the user may need to input data. The user may provide values for the following if they are know, otherwise the default values will be used:

- Allowable depletion
- Field capacity
- Actual evapotranspiration rate
- Average evapotranspiration rate

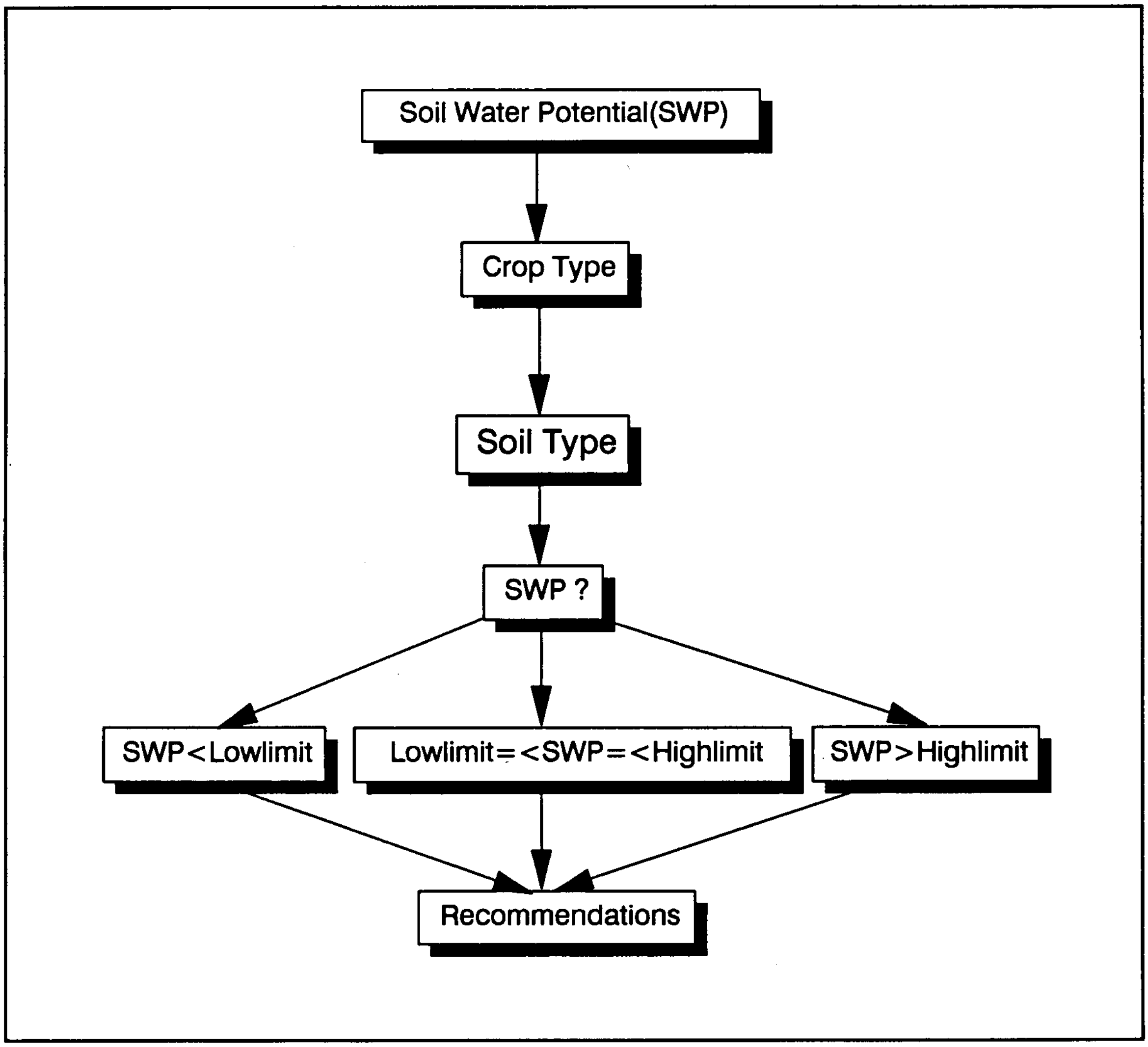

Figure 15 Information flow using SWP criterion

- Irrigation efficiency

An example rule using MAD is shown in Figure 22 and 23. From these figures, a statement which describes the probability of rain has been used in rules. Expert systems that mimic human behavior should operate with real-world situations and be able to reason using uncertain information. In dealing with this kind of uncertainty, we are not completely sure of a fact, but we have reason to believe that it is "probably" true. Coping with uncertainty, OSU Shell uses the confidence threshold which allows the user to set the minimum

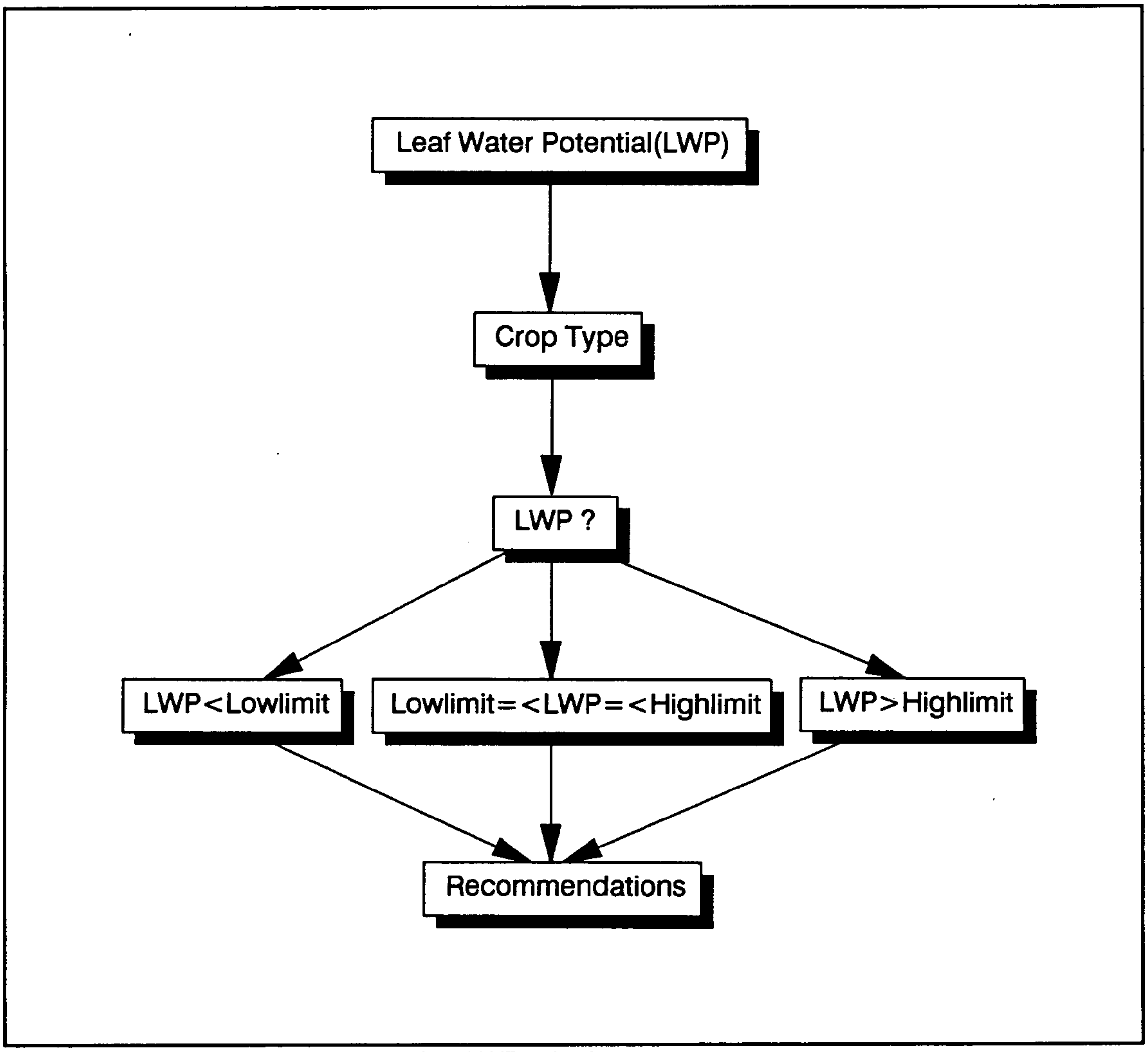

Figure 16 Information flow using LWP criterion

confidence level at which a line of reasoning will no longer be pursued.

If there is not any specific data available, how can CMX solve irrigation problems? In order to deal with these problems, CMX needs the user to input some general information about current crop and soil conditions. CMX will give some details for supplying necessary information. The user may be concerned about the following concepts:

- Crop growth stage
- Soil moisture level

```
rule    using SWP to make irrigation decision for wheat
if      you are interesting in making irrigation decision using SWP criteria
and     crop type is wheat
and     soil type sandy loam
and     you know the SWP value of the current crop and the SWP value is below -
        90 kPa.
then    recommendation(irrigation_now)
and     text("Irrigate right now. Otherwise, the crop yield will be severely reduced.")
```

Figure 17 A typical rule from the knowledge structure using SWP criteria

- Crop appearance
- Soil texture

After considering all these concepts and relations and acquiring knowledge from domain experts, CMX generates the irrigation decision table (Table 9). Based on the different growth stages, the decision trees which reflect the heuristic knowledge and expertise of the domain experts have been developed (Figure 24, 25, 26, and 27). Rules have been developed to reflect these trees. A typical rule is shown in Figure 28.

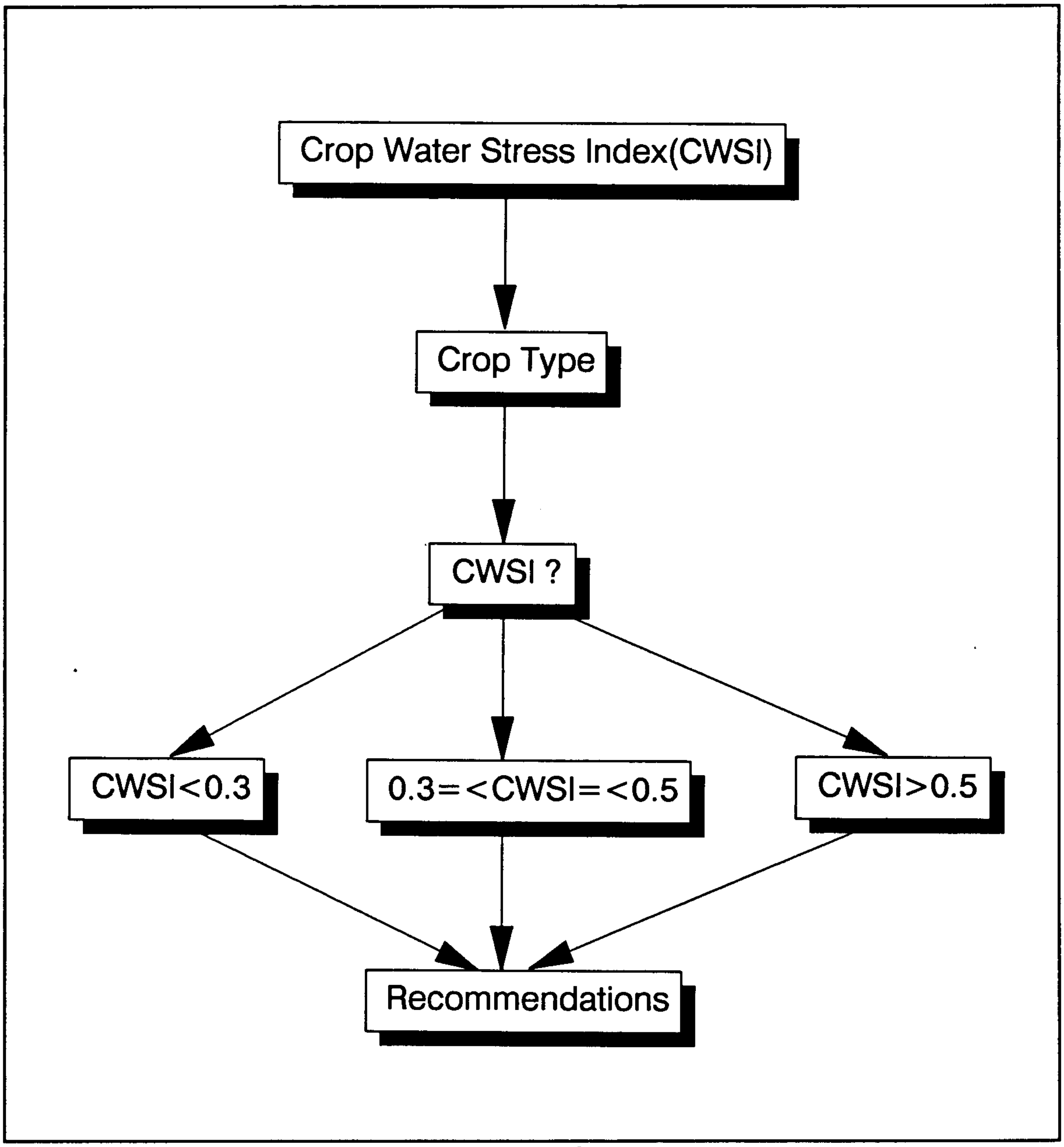

Figure 18 The knowledge structure using CWSI criteria

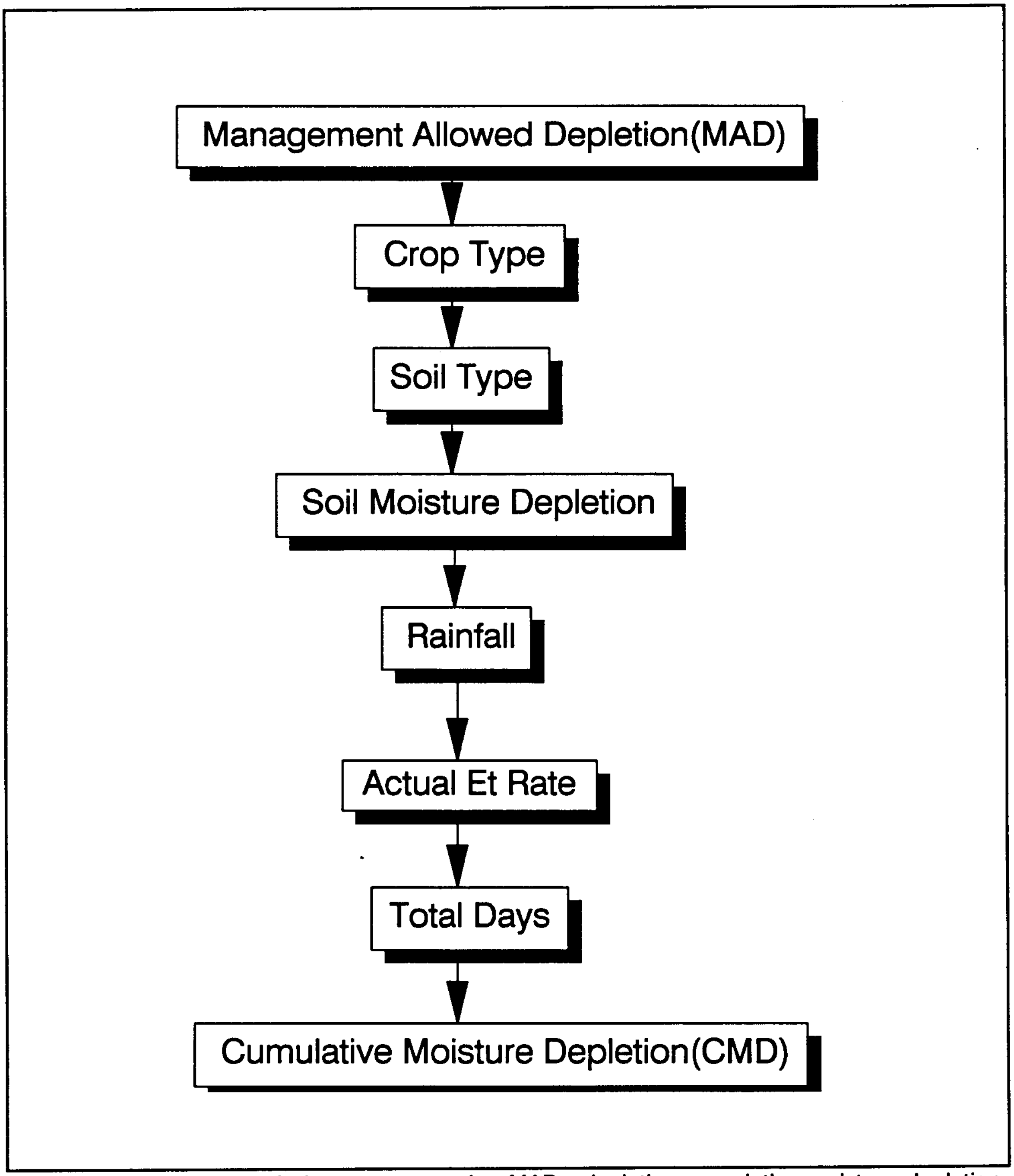

Figure 19 The knowledge structure using MAD-calculating cumulative moisture depletion

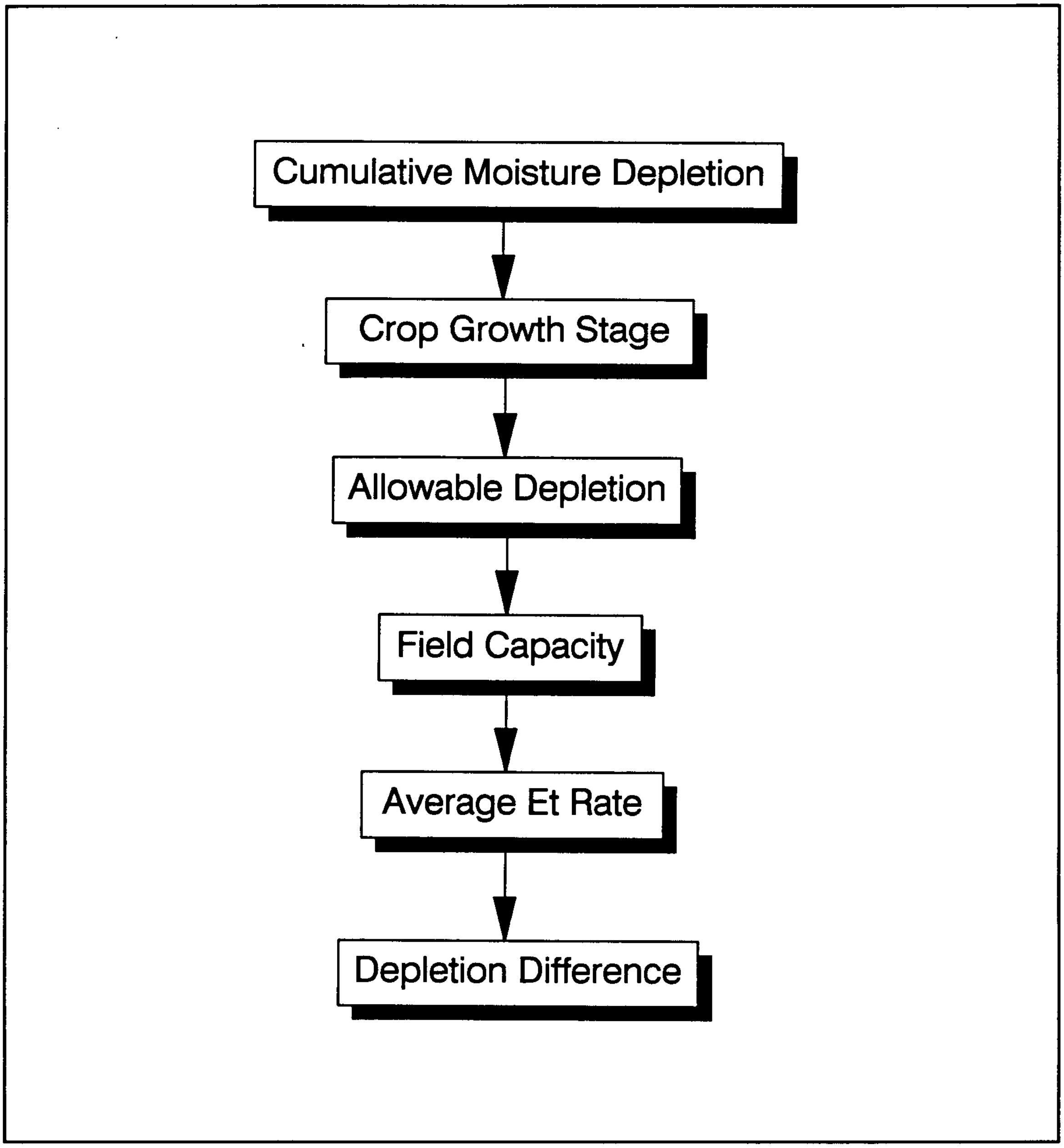

Figure 20 The knowledge structure using MAD-depletion comparison

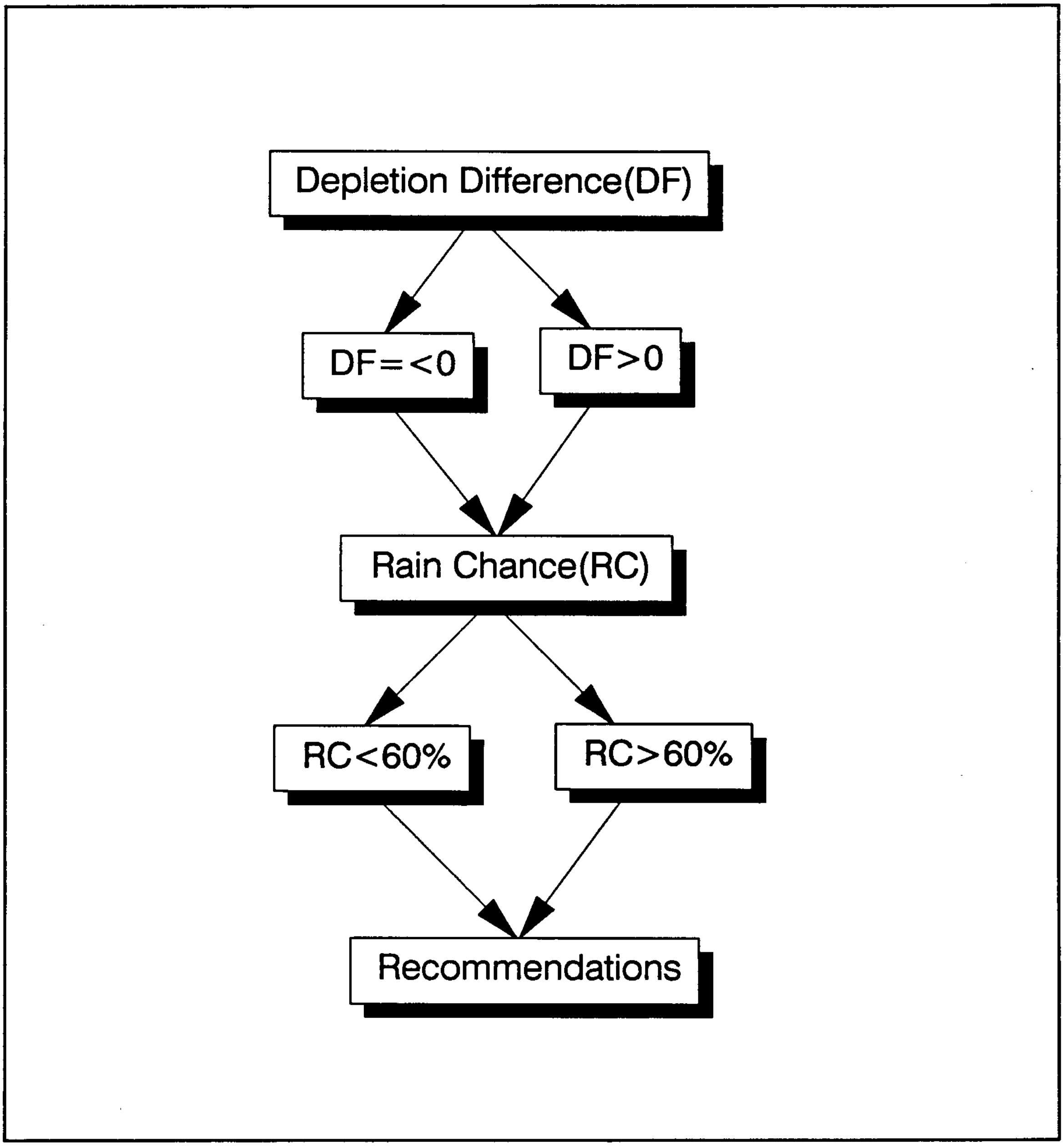

Figure 21 The knowledge structure using MAD-making decisions

```
rule    determining cumulative soil moisture depletion
if      you are using CMD to make irrigation decision
and     crop type is wheat
or      some other crops
and     soil type is silt loam
or      some other soils
and     you know some specific data
and     the effective rainfall is Rainfall mm
and     actual Et rate is EtRate mm/day
and     a total days since last irrigation is TotalDays day
and     CumulativeMoistureDepletion = (EtRate * TotalDays -Rainfall) mm
then    cmd(CumulativeMoistureDepletion)
and     text("The cumulative soil moisture depletion is CumulativeMoistureDepletion
        mm")
```

Figure 22 A rule for estimating cumulative soil moisture depletion

```
rule   determining when and how much to irrigate
if     cmd(CumulativeMoistureDepletion)
and    crop growth stage is tillering
or     some other growth stages
and    allowable depletion is AllowableDepletion
and    field capacity is FieldCapacity
and    average Et rate is AverageEtRate
and    DepletionDifference = (AllowableDepletion * FieldCapacity -
       CumulativeMoistureDepletion)
and    NumberOfDay = (AllowableDepletion / AverageEtRate)
and    DepletionDifference > 0
and    NumberOfDay > 2
and    the chance of rain in next 2 days < 60%
and    irrigation efficiency is IrriEfficiency
and    AmountOfWater = (AllowableDepletion / IrriEfficiency)
then   recommendation(AOW)
and    text("There are NumberOfDay days until the next irrigation. The total amount
       of water which needs to be irrigated is AmountOfWater mm. Please mark
       your calendar. The most critical stages are during tillering, booting,
       heading, and flowering. Water shortage during these stages can result in
       severely reduced yield. So you must concern about water stress at all
       these stages.")
```

Figure 23 An example rule for irrigation decision using MAD.

Table 9 Input data for irrigation decision

Crop growth stage	Soil moisture level	Crop appearance	Soil texture	Irrigate?
early	wet			no
early	moist			no
early	medium	ok	fine	no
early	medium	ok	coarse	yes
early	medium	wilting		yes
early	dry			yes
mid	wet			no
mid	moist			no
mid	medium	ok	fine	no
mid	medium	ok	coarse	yes
mid	medium	wilting		yes
mid	dry			yes
late	wet			no
late	moist		fine	no
late	moist		coarse	yes
late	medium	wilting		yes
late	medium	ok	fine	no
late	medium	ok	coarse	yes
late	dry			yes
harvest				no

The above knowledge representation for irrigation scheduling involves heuristics that effectively limit the search for solutions. Expert systems use heuristics to undertake some tasks that are typically difficult and poorly understood.

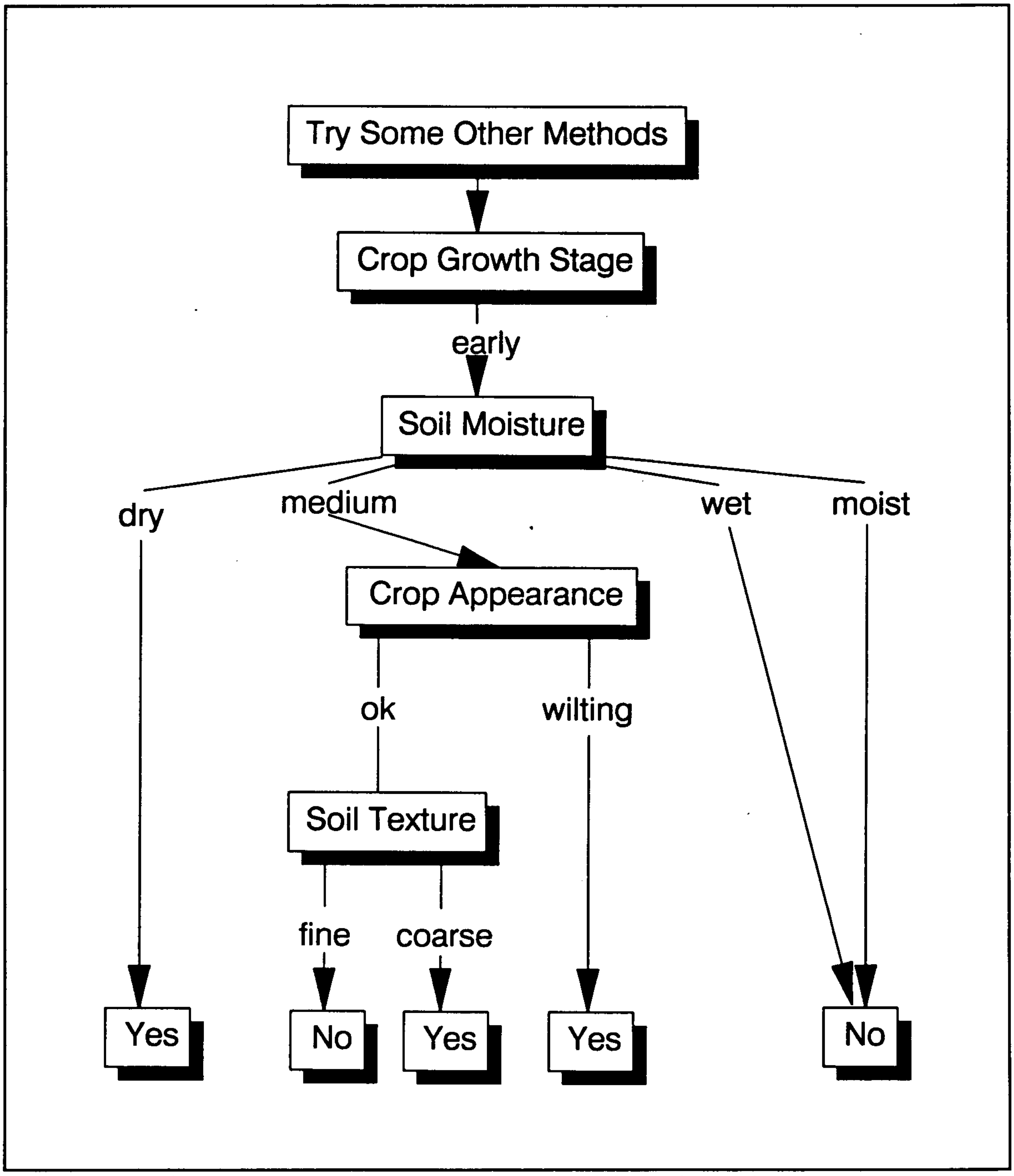

Figure 24 The knowledge structure using general information-early stage

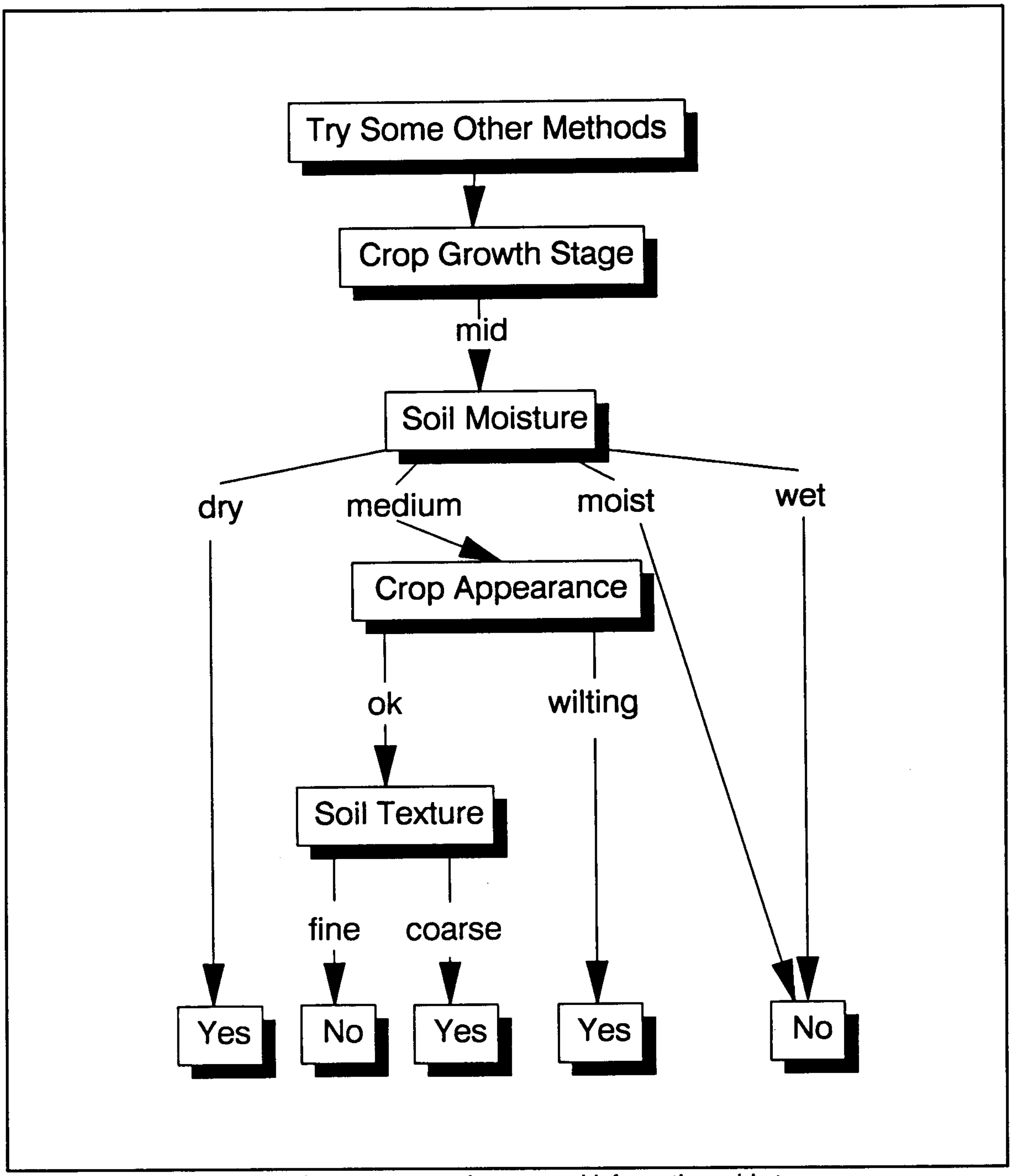

Figure 25 The knowledge structure using general information-mid stage

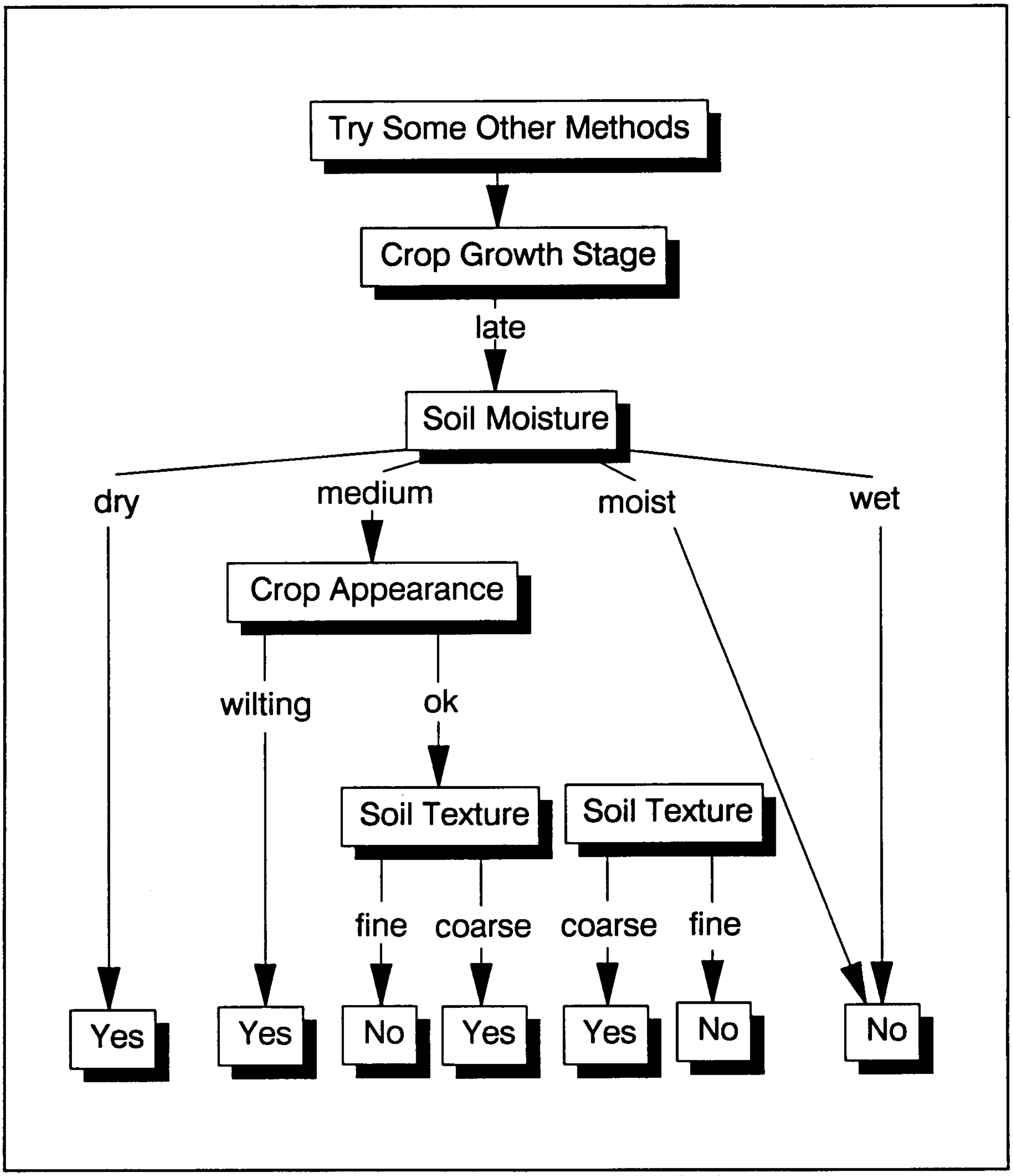

Figure 26 The knowledge structure using general information-late stage

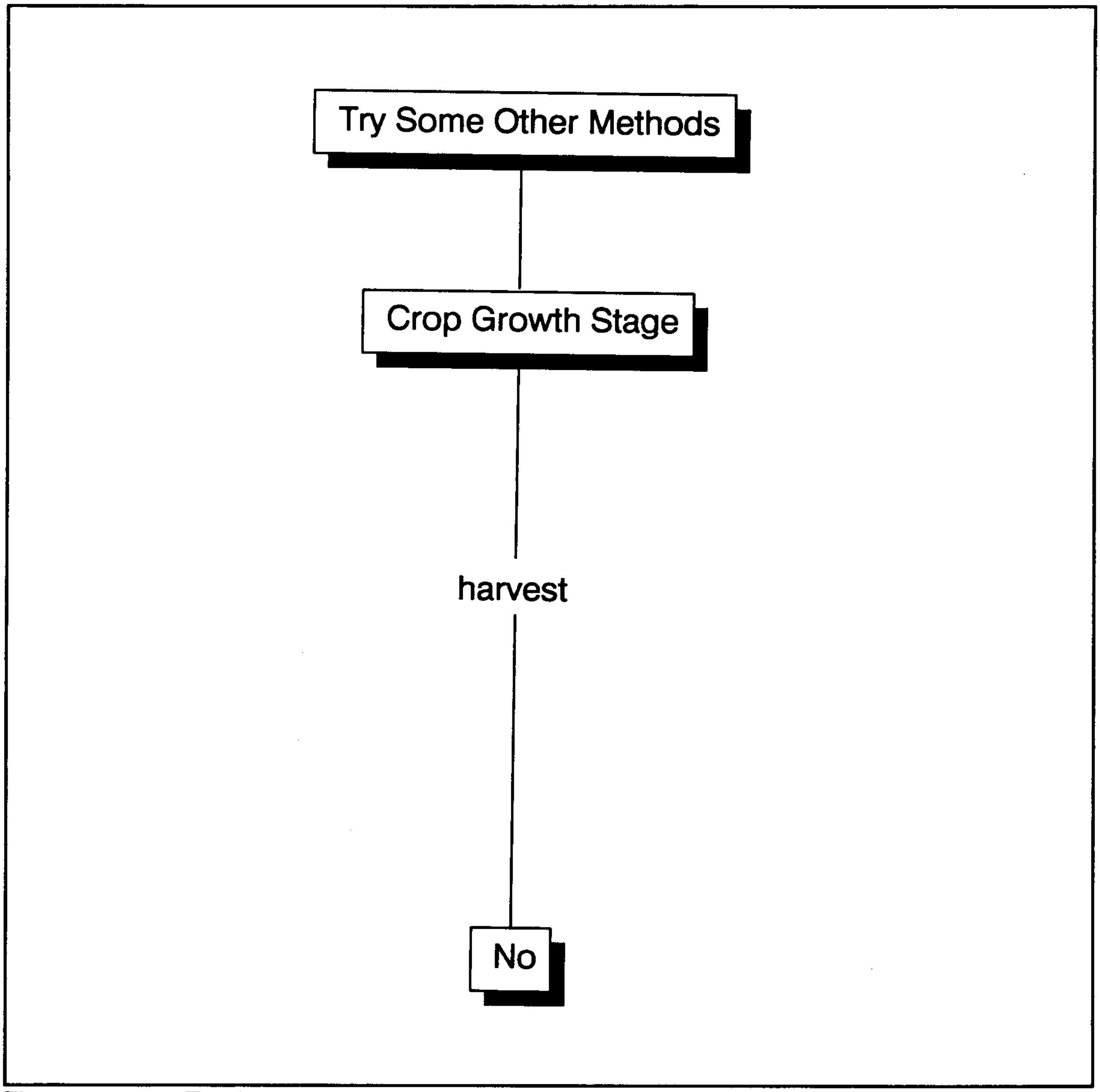

Figure 27 The knowledge structure using general information-harvest stage

rule	generating the irrigation advice using general information
if	you are using some other methods to make irrigation decision instead of irrigation timing criteria
and	crop growth stage is early
or	crop growth stage is mid
or	crop growth stage is late
and	soil moisture level is medium
and	crop appearance is ok
and	soil texture is coarse
then	recommendation(irrigation)
and	text("You need to irrigate now.")

Figure 28 A rule for irrigation decision using general information

4.4.3.2 Fertilization

The system for fertilization management operates also as a series of antecedent-consequent clauses expressed as IF:THEN statements in rules, which have a number of possible outcomes, depending on the conditions given in Figure 29, 30, and 31.

Most essential to any effective control strategy is the correct identification of nutrient components and nutrient concentration data. The CMX, therefore, first determines which nutrient the user wants information about. In our case, three nutrients have been considered:

- Nitrogen
- Phosphorus
- Potassium

CMX asks the user whether there is soil nutrient concentration data available from the soil test. If the answer is yes, the system will ask the user to provide the following data:

- Current soil nitrogen concentration level
- Current soil phosphorus concentration level
- Current soil potassium concentration level

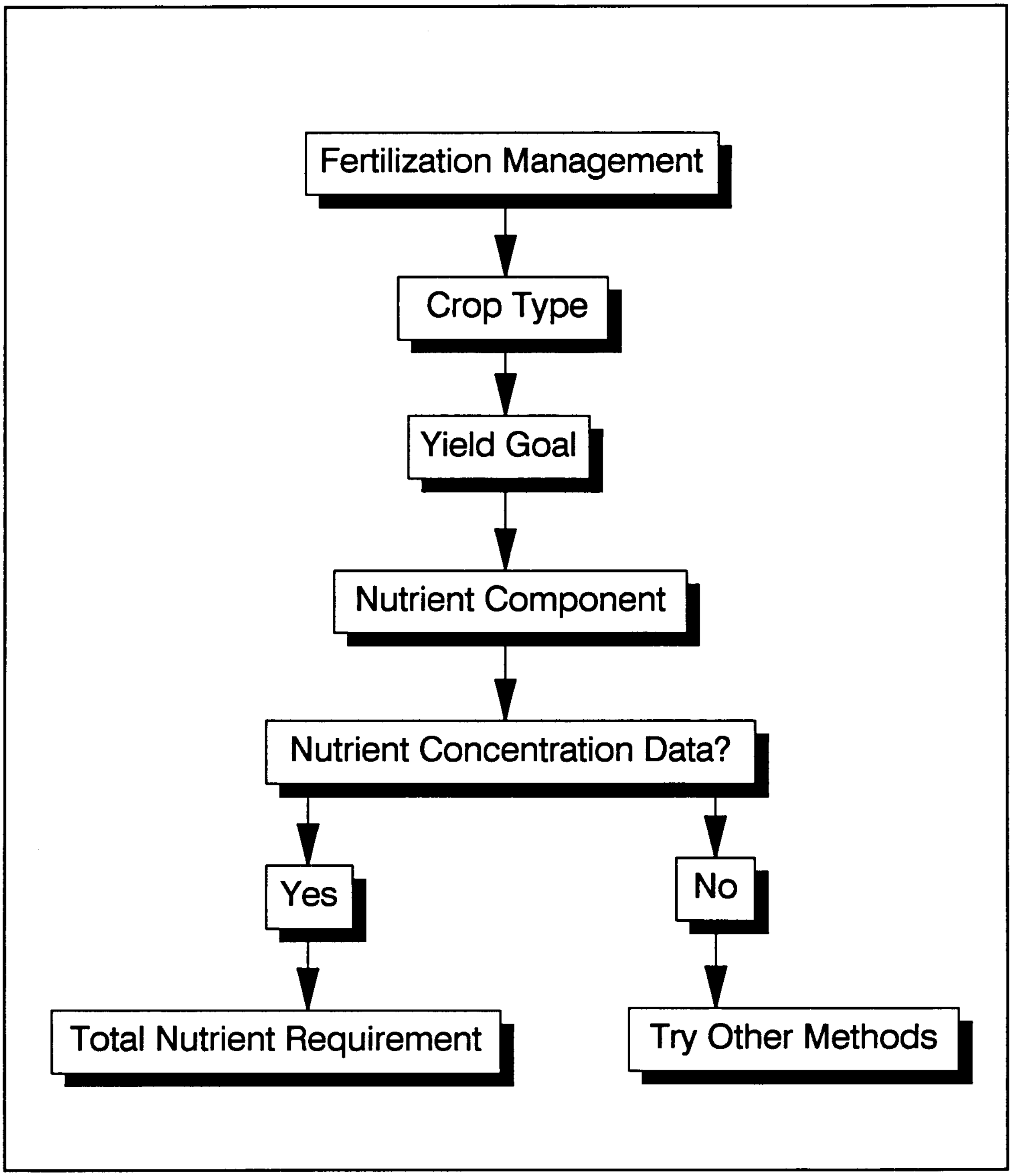

Figure 29 The flow diagram of knowledge base for fertilizer management-stage one

In this case, the system uses soil nutrient balance methods to make fertilizer decisions. Otherwise, the system will use current crop conditions (deficient symptoms) to give the fertilization advice to the user. Example rules for fertilizer management using simple information are shown in Figure 32.

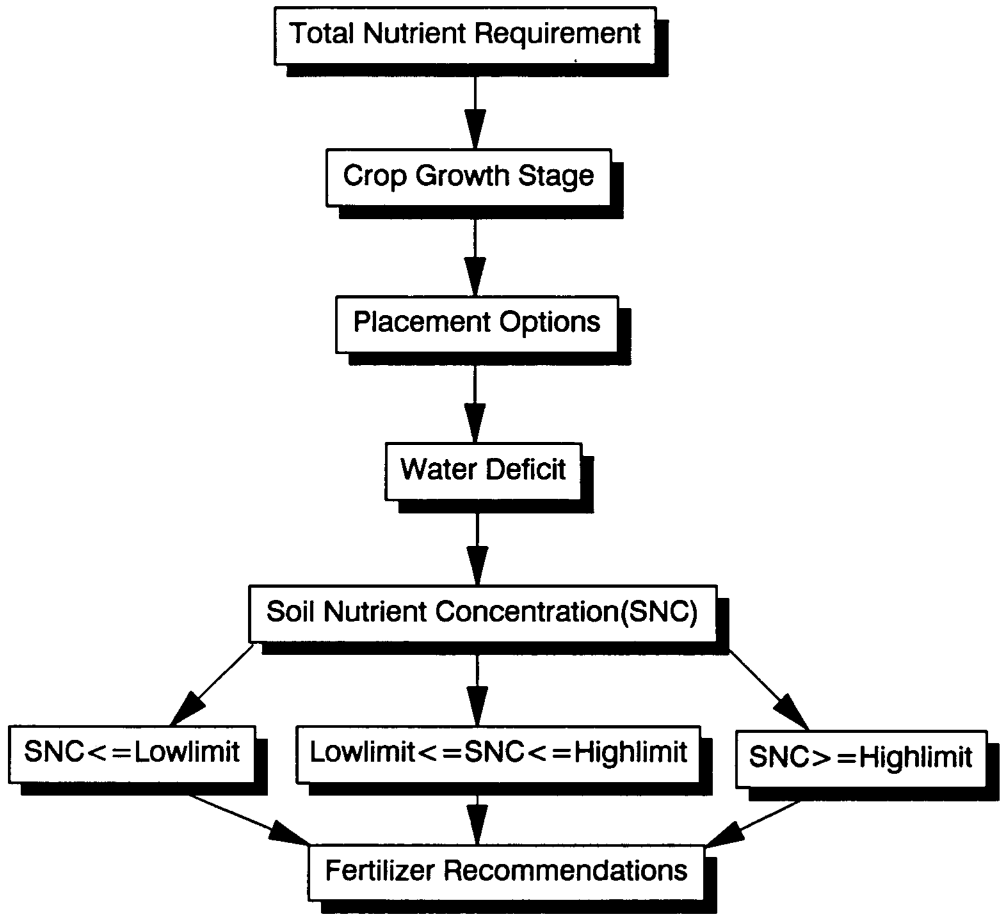

Figure 30 The flow diagram of knowledge base for fertilizer management-stage two

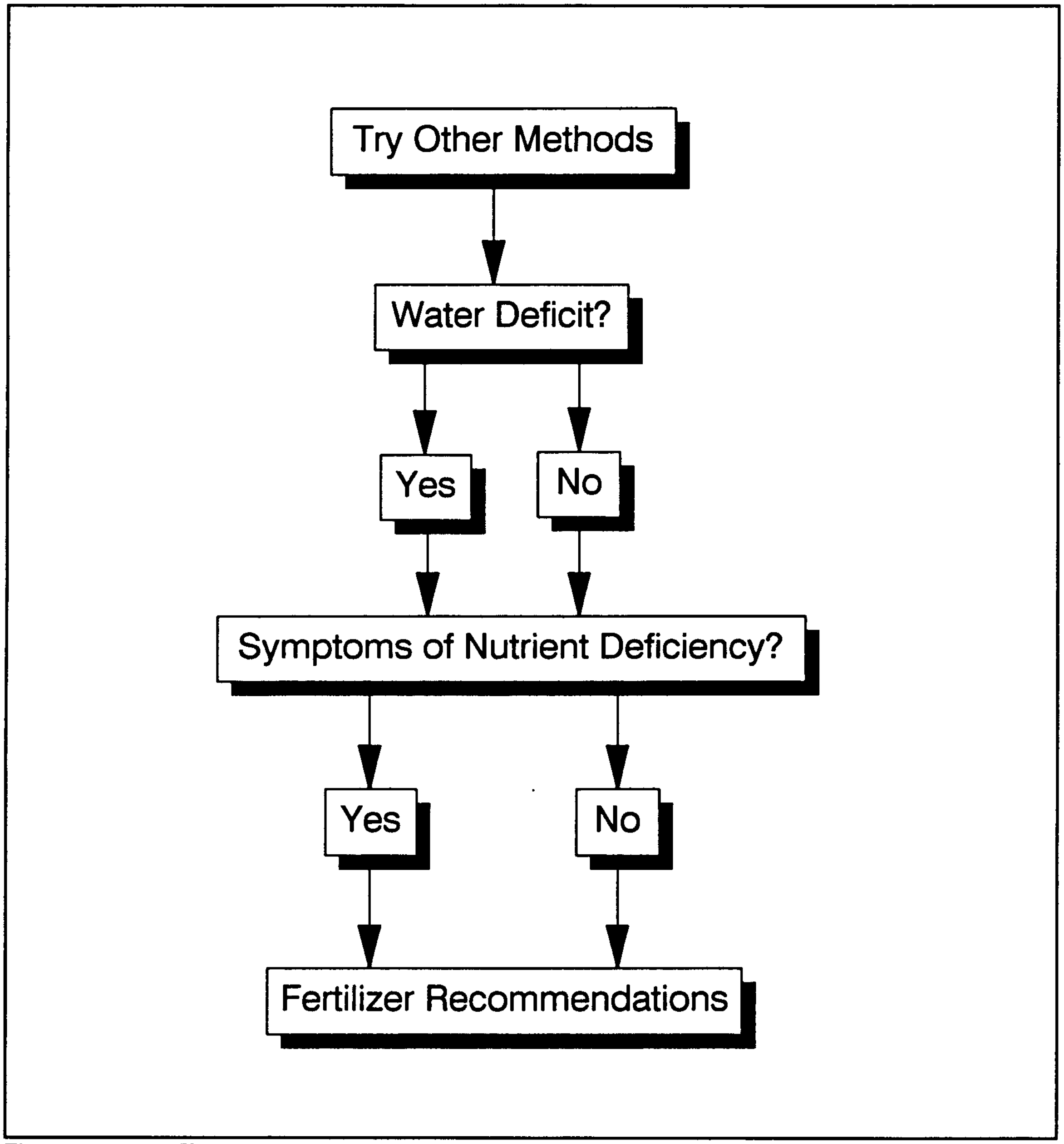

Figure 31 The flow diagram of knowledge base for fertilizer management-stage three

rule	determining total N requirement
if	you are dealing with fertilization management
and	crop type is wheat
and	specific wheat type is winter wheat
or	specific wheat type is spring wheat
and	your yield goal is *YieldGoal*
and	nutrient component is nitrogen
and	you don't have current soil nutrient concentration data
and	LowLimit(nitrogen requirement) = YieldGoal * 2.4
and	HighLimit = YieldGoal * 2.7
then	other_method_n(other_method_n)
and	text("Don't worry about no soil test data available. As long as you provide some basic information a little later, I will give you some help in the fertilizer decision making. The total nitrogen requirement is about LowLimit - HighLimit pounds per acre for your yield goal.
rule	making decision for N fertilizer
if	other_method_n(other_method_n)
and	the crop is suffering from water deficit
and	wheat plants become light green and then yellow(This symptom starts with the oldest leaves and progresses to the youngest leaves. Older leaves eventually turn brown and die while the limited supplies are allocated by the plant to the newest growth.)
then	recommendation(add_N)
and	text(" At first, you need to irrigate to relieve the water stress. If the symptoms of nitrogen deficiency is still existing, you may apply a certain amount of nitrogen to the crop.")

Figure 32 Example rules for fertilizer management using simple information

5. DISCUSSION

5.1 Testing

During the testing stage the level of performance and utility of the program were established. The testing stage included verification, partial validation and overall evaluation.

5.1.1 Verification

Verification occurs throughout the entire development process. Verification proves that the methods within the program are reasonable relationships. It ensures that the knowledge of the expert is accurately mimicked.

During the development of CMX, each rule was verified after formulating the rule, ensuring that it embodied adequate knowledge which contained clear facts and true relationships. Available knowledge of experts was mimicked as accurately as possible. The production rules provide a good way to present the knowledge clearly. OSUI Shell provides strong editing and debugging facilities. All these features reduced errors in representing knowledge. After running CMX program, final results showed that all rules in the knowledge base presented the knowledge of the expert quite well and brought satisfactory and consistent solutions.

5.1.2 Validation and Evaluation

Validation determines the correctness of the ES on a case-by-case basis. An effective validation procedure is critical to the overall success and acceptance of the program. During validation the following features are of concern: 1) correctness, consistency, and completeness of the inference rules; 2) ability of the control strategy to consider information in the order that corresponds to the expert's problem solving process; 3) appropriateness of information concerning how conclusions are reached and why certain information is required; and, more importantly, 4) agreement of the ES's solutions to the domain expert's corresponding solutions. The first three features have been considered throughout the implementation of CMX.

Validation is a continuous process requiring that the recommendations be accurate for a specific user's case. Validation is enhanced by allowing others to critically review the ES and make recommendations for improvements. In order to validate CMX, irrigation and fertilization scenarios were sent to domain experts who were asked to evaluate all these scenarios. These scenarios were used to compare the conclusions of the ES with those of the domain expert. The survey results were very encouraging. The survey result for irrigation scenarios is shown in Appendix 1. These irrigation scenarios were randomly selected from the knowledge base. The result shows that all scenarios are realistic and there is 72% coincidence with the domain expert in 36 scenarios. This result indicates that most of the knowledge base in the irrigation field is valid because validation through direct comparison with experts gives the most effective way to insure that the system provides the intended results and reflects the state of knowledge in the domain.

Some criteria which can be used to verify the success or failure of an expert system are available. Criteria for performing expert system validation include the following:

- *Conclusions*. Validating conclusions is an obvious method for increasing the confidence in the expert system's behavior. This is essentially equivalent to evaluating the input-output behavior of the expert system, as in traditional software testing. In order to validate conclusions, a consultative session was started with OSU Shell. OSU Shell first checks to see if a knowledgebase file has been loaded. It then tries to solve for one top-level goal by applying what it currently knows to the rules in the knowledgebase. As the inference engine comes to askable rule facts it does not yet know about, it will ask the user to provide the information. OSU[redacted] Shell will attempt to find a solution and report it, if one exists; otherwise it will report that it is unable to find a solution to the given goal. Reviewing this process ensures that the inference engine makes intended and consistent conclusions.

- *Reasons*. Validating the reasons for arriving at conclusions is just as important as validating the conclusions themselves. This increases our confidence in the expert system and our belief that it is, indeed, a clone of the expert. *Execution tracing* was used to check if the reasons for arriving at conclusions are necessary and adequate. Finally, an expert was used to make sure that all reasons are valid for generating recommendations.
- *Reasoning Methods*. We should validate reasoning and inference methods as well as reasons. This provides insight into how the knowledge is operated on and tests the operation of the inference engine. OSU[redacted] Shell provides a run-time trace facility for monitoring the execution of the inference engine while running CMX knowledge base. This feature was used to see how the inference engine arrived at the conclusion, case by case. This allows a clear understanding of which factors were influencing the results.

We can also assess the overall validity of an expert system, i.e., whether its appearance and performance are acceptable to those who will be using it. Some overall validity criteria which can make an acceptability judgement for an expert system include the following:

- *Face Validity*. CMX looks and feels good in terms of its knowledge-base, inference structure, user interface, and output.
- *Coverage*. CMX covers quite important problems in its knowledge domain. For example, irrigation and fertilization problems, important subjects in crop management, have been included in CMX. CMX also covers most important concepts in the irrigation and fertilization domains.
- *Appeal*. This system can be easily used. The user interface is sufficiently well developed to provide convenient interaction with the system. Questions are asked in a logical order, mimicking an interview with an expert. The system

gives the user a feeling of dealing with an expert rather than a machine.

- *Performance*. The performance of CMX matches reality well. For instance, this system gives the user a diversity of recommendations about when to irrigate and what amount of water to apply. These kinds of recommendations are useful in maximizing yield potential of the crop.

Validation increases one's confidence in the future behavior of the system, but there can never be total certainty about the correctness of any expert system. The above criteria and other criteria like *precision*, and *reliability* are necessary to consider in the future evaluations. These evaluations should occur in the field over several growing seasons.

Even with the best attempts at validation, an expert system may inevitably make mistakes in unexpected situations, just like a human expert.

5.2 Appropriateness, Usefulness and Performance

5.2.1 Appropriateness

The CMX is a good candidate for expert systems application, because:

- it doesn't fully use a formal algorithm for generating solutions for the irrigation and fertilization problem;
- it relies on experience, intuition, and heuristics when making irrigation and fertilization decisions;
- it requires symbolic (conceptual) reasoning;
- it represents and uses the domain knowledge; and
- it gives detailed explanations for irrigation and fertilization decisions.

Production rules present the knowledge for CMX well. The production rules (e.g., if/then statements) appropriately describes relationships about irrigation and fertilization management. In this rule-based expert system, the domain knowledge is represented as a set of rules that are checked against a collection of facts or knowledge about the current situation. When the IF portion (premise) of a rule is satisfied by the facts, the conclusion specified by the THEN portion is justified. The conclusion of rule can be used to get irrigation and fertilization decisions for the user. Rules in the CMX present a number of desirable features. First, they are straightforward and seem to correspond to the way in which expert discuss their own knowledge. Second, rules can describe how the system reacts to incoming data, often without considering in advance about the order in which actions should be taken by the reasoning system.

Results show that production rules capture domain knowledge appropriately and CMX performs well.

5.2.2 Usefulness and performance

CMX successfully delivers the irrigation and fertilization recommendations to the user. This system can tell the user when and how much water to apply. Also, this system advises the user when to apply fertilizer, what amount of fertilizer to apply, and how to apply fertilizer. Thus, it provides a valuable tool for users to more effectively make decisions concerning optimal management strategies for maximizing profits and minimizing environmental impacts. For example, using this system can prevent users from over-irrigation, which increases cost and decreases yield; using this system can keep users from over-fertilization which causes profit loss and environmental pollution from leaching of nutrients. Therefore, this system can help users to achieve their goals in economic and/or environmental terms. Thus, this system is a very useful tool in crop optimal management.

In order to evaluate the performance of CMX, 36 irrigation scenarios were randomly selected from the knowledge base and sent them out to the experts for feedback. Comparing with the experts' recommendations, this system achieved 72% agreement. The experts thought that all scenarios are realistic and practical. From this point of view, this represented real and intensive knowledge and delivered real advice like domain experts. For instance, this system took into account a lot of factors such as crop type, soil texture, crop growth stage, field capacity, soil moisture depletion, irrigation strategies, and irrigation timing criteria.

A total of 28% differences between domain experts and CMX existed in the survey. Those difference reflected different comments on the same topic, just as different human experts may have different opinions on the same topic. There are not wrong answers among those differences.

5.3 Building Tool Validation

OSU| Shell used in the CMX is a successful building tool. This shell performs well the following major functions:

- Assists in building the knowledge-base by allowing the developer to insert knowledge into knowledge representation structures.
- Provides methods of inference or deduction that reason on the basis of information in the knowledge-base and new facts input by the user.
- Provides an interface that allows the user to set up reasoning tasks and query the system about its reasoning strategy.

As an expert system building tool, OSU| Shell provides extensive support facilities, including the debugging aids, knowledge base editor, I/O facilities, and explanation mechanism. OSU| Shell is capable of describing a wide variety of knowledge domains. It can process numerical and symbolic knowledge. For example, OSU| Shell successfully presents the adequate knowledge in irrigation and fertilization areas which are associated with a variety of facts and relationships. OSU| Shell makes it easy to edit and debug the knowledge base. For instance, the user can easily get access to or exit the knowledge editor. Without exiting the shell, the system can immediately shift to executive window after editing and debugging the knowledge base. The production rules used in CMX results in a readable knowledge base. The knowledge base can be significantly modified and changed without major reprogramming.

5.4 Difficulties in Development of an Expert System

During the development of CMX, several types of difficulties and limitations were encountered. Expert systems are not very good at representing temporal or spatial knowledge. Representations of this type can require large amounts of memory to keep track of the state of things at various points in time or to record the spatial relations between different groups of objects.

Human experts may use common sense or general knowledge about the world. If this type of knowledge is crucial to solving a problem, the knowledge engineering approach will most likely fail.

Expert systems have a very domain of expertise and hence their operation is not as robust as the users might want. Because of this, expert systems have difficulty recognizing the limits of their ability. When pushed beyond their limits or given problems different from those for which they were designed, expert systems can fail to generate an appropriate recommendation.

Expert systems also have difficulty dealing with erroneous or inconsistent knowledge. This is because most expert systems rely on a body of rules that represent abstracted knowledge of the domain and aren't able to reason from basic principles to recognize incorrect knowledge or reason about inconsistencies.

Expert system building tools also have certain limitations that affect system design and development. The most serious limitation of expert system building tools is their inability to perform knowledge acquisition. Knowledge acquisition is the major bottleneck in expert system development; it's tedious and time-consuming to extract knowledge from the an expert and incorporate it into a large knowledge base (Waterman, 1986).

6. CONCLUSIONS

CMX has been developed using a development strategy which consists of identification, conceptualization, formalization, implementation, and testing. This development strategy has proven to be an effective approach. This development strategy allowed step-by-step goal development and guided each task in each development step.

The program for generating irrigation and fertilization recommendations is an example of one way that expert system technology can be successfully applied to the solution of everyday problems in resource management, because the problem relies heavily on knowledge describing the relevant factors involved in irrigation and fertilizer scheduling and the system provides effective information, advice, and support to the user. In addition, the incremental development methodologies used to create expert systems allow gradual expansion of the scope of the system's knowledge and thus control of the complexity surrounding the decision making involved in generating irrigation and fertilizer recommendations. Furthermore, we were able to program the system with sufficient knowledge to enable it to focus its attention toward relevant information only, thus reducing the problem space to a manageable size and significantly improving the efficiency of the system.

CMX provides easy access to information and expertise for making irrigation and fertilization management decisions. After considering many factors such as crop growth stage, soil texture, soil moisture depletion, soil nutrient concentration level, and yield goal, CMX, like a human expert, delivers advice on irrigation and fertilization scheduling. An effort has been made to assemble the best available information and expertise.

CMX provides a prototype for the development of similar knowledge bases for the management and control of other crops such as alfalfa, cotton, maize, potato, and soybean. These knowledge bases can be integrated into the

OSU integrated Crop Management Decision Support System (OSU/ICM), a complex computerized system, to deliver the fruits of technology and the acquired knowledge of research to the crop grower. The development of CMX provided an expanded base for the OSU/ICM.

CMX provides a valuable tool for the growers to more effectively make decisions concerning optimal management strategies for maximizing profits and minimizing environmental impacts. By using expert system concepts and technology, CMX provide expertise and integration of diverse aspects of crop management to the user.

7. RECOMMENDATIONS

7.1 Combining Deficit Irrigation Strategy

If CMX contained the deficit irrigation strategy, the current system would be more powerful. Why do we need to develop the knowledge base for deficit irrigation management? The potential benefits of deficit irrigation derive from three factors: reduced costs of production, greater irrigation water use efficiency and the opportunity costs of water (English et al., 1991). Deficit irrigation is widely practiced, particularly in water short areas. Deficit irrigation has been proven to be a valid and useful strategy.

Deficit irrigation managers must decide what level of deficit to allow and must recognize when that level has been reached. They may choose to allow deficits to occur at some times and not others. It is my opinion that all these tasks can be completed by combining an expert system with information from the crop model. In other words, we can make the deficit irrigation expert system available by a linkage with information output from the wheat model. Taking water stress and crop yield considerations into account, this system can determine when the level of allowable stress will be reached and how much water to apply.

7.2 Adding Pest Management Expert System

Pest management is essential in the crop production in order for farmers to increase profits. Many expert systems have been developed as decision aids in the crop insect pest management such as soybean pest management, alfalfa pest management, and cotton pest management. But no expert system for wheat pest management is available now. It is my opinion that an expert system for wheat pest management can be developed by using the expertise of entomologists in wheat production.

An entomologist frequently has the ability to identify the insect, examine insect populations in the field, and estimate the damage rate caused by those populations. A consultant or extension entomologist must select an insecticide and application rate if it is determined that a population is above a treatment threshold. Expert systems are capable of mimicking the thought processes of an expert, thus providing the problem solving abilities of the expert to the non-expert. Thus, we can develop an expert system for wheat pest management using the heuristic knowledge of entomologists. At least, this system should do the following:

- Help the user how to identify the insect type based on the input from the user.
- Help the user to select an insecticide and application rate in basis of information from the user.
- Provide advice to the user when to apply insecticide if the system incorporates with the crop model.
- Determine the yield loss by effects of insect populations at various periods during the season if the system is combined with a crop model.

7.3 Coupling Neural Networks with Expert Systems

CMX is a rule-based expert system for irrigation and fertilization management. Current rule-based expert systems provide a number of advantages over "conventional" approaches for a number of problem types, particularly in situation where the problem involves symbolic knowledge and/or uncertain information. These advantages include rapid development, improved maintainability, capabilities for explanation of reasoning behavior, and ease of use. These systems attempt to model the *software of the mind*, in that they mimic the human expert's reasoning process about the particular problem being considered. However, current rule-based systems have a number of limitations when considered as true " intelligent" systems (Bolte, 1989). First, expert behavior is only partially explained in terms of inferential reasoning; a very large part of human expertise arises from being able to *recognize patterns* in input situations and act accordingly. Second, these systems lack capabilities for generalizing knowledge to response to new situations; if the problem's solution lies outside of that defined by the knowledge engineer during the construction phase of knowledgebase development, the system will not able to respond. Finally, these systems lack capabilities for *automatic learning*; the knowledgebase must be "hand crafted" and tend to be static and unable to readily incorporate new knowledge as it becomes available or out-of-date.

Neural networks offer an alternative to rule-based systems for developing intelligent applications. The technology of neural networks has allowed their successful application to a number of problems. While a number of basic network architectures have emerged, all are based on the same concept: connecting a large number of simple processing elements in a massively parallel, highly distributed processing environment. Neural networks are *biologically inspired*; that is, they are composed of elements that perform in a manner that is analogous to the most elementary functions of a biological neuron. Similarly, they are organized in a manner which, to a certain extent, is patterned after the organization of neurons in a biological brain. They display characteristics which are similar to those of biological brains: e.g., they learn from experience, generalize new situations from views of previous situations, abstract essential characteristics from "noisy" input, and can withstand partial damage to their structure. All of these characteristics result from the fundamental *structure* of neural networks, rather than any "human-imposed" control strategy or clever software design. Because of the similarities between natural and artificial neural networks, both in design and in processing capabilities, artificial neural networks can be considered as simulations of the *hardware of the mind.*

Expert systems try to model the software of the mind while neural networks attempt to model the hardware of the mind. The combination of the two systems would be more robust than either acting alone, and it would follow the highly successful model provided by biological evolution. Combining neural networks with CMX would potentially provide a more appealing and powerful decision tool for the growers.

Bibliography

Ackerson, R.C., D.R. Krieg, T.D. Miller and R.G. Stevens. 1977a. Water relations and physiological activity of potatoes. J. AM Soc. Hort. Sci. 102(5): 572-575.

Ackerson, R.C., D.R. Krieg, T.D. Miller and R.E. Zartman. 1977b. Water relations of field grown cotton and sorghum: temporal and diurnal changes in leaf water, osmotic and turgor potential. Crop Sci. 17(1): 76-80.

Aparicio-Tejo, P.M., M.F. Sanchez-Diaz and J.I. Pena. 1980. Nitrogen fixation, stomatal response and transpiration in Medicago sativa (alfalfa), trifolium repens and trifolium subterranean (white clover subterranean clover) under water stress and recovery. Physiol. Plant. 48(1): 1-4.

Baker, D.N., J.R. Lambert, and J.M. Mckinion. 1983. GOSSYM: a simulator of cotton crop growth and yield. S.C.Agric. Exp. Stn. Tech. Bull. 1089, 134pp.

Balestrieri, M. 1989. A knowledge based system for maize crop fertilization. ACM 0-89791-320-5/89/0006/0695.

Barlow, E.W.R., L.Boersma and J.L. Young. 1977. Photosysthesis, transpiration and leaf elongation in corn seedling at suboptimal soil temperatures. Agron. J. 69(1): 95-100.

Barrett, J.R., J.B. Morrison, and L.F. Huggins. 1985. Artificial intelligence and expert system in agricultural research and education. ASAE Paper No. 85-5516, ASAE, St;Joseph, MI 49085.

Bolte, J.P. 1989. Applications of neural networks in agriculture. ASAE Paper No. 897591. ASAE, St, Joseph, MI 49085.

Boyer,J.S. 1970. Leaf enlargement and metabolic rates in corn, soybean, and sunflower at various leaf water potentials. Plant Phsiol. 46: 233-235.

Brady, R.A., S.M. Goltz, W.L. Powers and E.T. Kanemasu. 1975. Relation of soil water potential to stomatal resistance of soybeans. Agron. J. 67(1): 97-99.

Broner, I., J.P. King, and A. Nevo. 1990. Structured induction for agricultural expert systems knowledge acquisition. Computers and Electronics in Agriculture, 5(1990) 87-99.

Brown, D.A., R.H. Bendedict and B.B. Bryan. 1955. Irrigation of cotton in Arkansas. Bulletin 552. Arkansas Agric. Exp. Sta.

Buchanan, B.G., D. Barstow, R. Bechtal, J. Bennett, W. Clancey, C. Kulikowski, T. Mitchell, and P.A. Waterman. 1983. Construting an expert system. In Building Expert Systems. Reading, Mass.: Addison-Wesley.

Calvin, D.D., E.G. Rajotte, and M.C. Saunders. 1989. Approaches to the development and implementation of knowledge-based systems in agriculture and natural resources: a global perspective. AI Applications 3(3): 57-58.

Campbell, C.A. and W.S. Ferguson. 1969. Influences of air temperature, light intensity, soil moisture stress and soil aeration on moisture use by wheat. Canadian J. of Plant Sci. 49: 129-137.

Clarke, N.D., G.E. Miles, J.R. Barrett, E.P. Christmas, and D.H. Doster. 1987. Coupled expert system and simulation to assess alternative crops in Indiana. ASAE Pater No. 87-3535, ASAE, St. Joseph, MI 49085.

Cook, R.J. and R.J. Veseth. 1991. Wheat health management. Plant Health Management Series. APS press. The American Phytopathological Society, St. Paul, MN 55121.

Day, A.D. and S. Intalap. 1959. Don't stress your wheat for water. Progressive Agric. in Arizona. 21(5): 8-10.

Engel, B.A. and D.B. Beasley. 1987. DSS: an expert system as an educational aid. ASAE Paper No. 87-5044, ASAE, St. Joseph, MI 49085.

Engel, B.A., D.D. Jones, J.R. Wright, and S. Benabdallah. 1991. Selection of an expert system development shell. AI Applications 5(1): 15-21.

English, M.J., J.T. Musick, and V.V.N. Murty. 1990. Deficit irrigation. In Managment of Farm Irrigation Systems. ASAE monograph: 631-663.

Even, M., R. Monodor, and D. Flaten. 1989. Expert systems and farm management. Canadian Journal of Agricultural Economics 37: 639-666.

Evens, M., R. Mondor, and D. Flaten. 1990. Using expert system to generate fertilizer recommendations. AI Applications 4(2): 3-10.

Fulton, J.M. 1970. Relationship of root extention to the soil moisture level required for maximum yield of potato, tomatoes, and corn. Canadian J. of soil Sci. 50: 92-94.

Garton, L.R. and A.D. Barefoot. 1959. Irrigation experiments at Altus and EI Reno. Bulletin B-534. Oklakoma Agric. Exp. Sta.

Hagan, R.M. and J.I. Stewart. 1972. Water deficit irrigation design and programming. J. Irrig. and Drain. ASCE 98(2): 215-237.

Halterman, S.T., J.R. Barrett, and M.L. Swearingin. 1988. Double cropping expert system. Transactions of ASAE 31(1): 234-239.

Hanson, E. G. 1967. Influence of irrigation practices on alfalfa yield and consumption use. Bulletin 514. New Mexico Agric. Sta.

Hatfield, J.L. 1983. Evapotranspiration obtained from remote sensing methods. In Advances in Irrigation, ed. D.Hillel, 2: 395-416. New York: Academic Press.

Hayes-Roth, F., D.A. Waterman, and D.B. Lenat. 1983. Building expert system. Addison_wesley. Publishing Cc., Inc., Reading, MA.

Hiler, E.A. and R.N. Clark. 1971. Stress day index to characterize effects of water stress on crop yields. Transactions of ASAE 14(4): 757-761.

Hobbs, E.H., K.K. Krogman and L.G. Sonmor. 1963. Effects of levels of minimum available soil moisture on crop yields. Canadian J. of Plant Sci. 43: 441-446.

Hoffman, J.G., T.A. Howell, K.H. Soloman. 1990. Management of Farm Irrigation Systems. ASAE monograph. ASAE, St. Joseph, MI 49085.

Huggins, L.F., J.R. Barrett, and D.D. Jones. 1986. Expert systems: concepts and opportunities. Agricultural Engineering 67(1): 21-23.

Idso, S.B., K.L. Clawson, and M.G. Anderson. 1986. Foliage temperature: effects of environmental factors with implications for plant water stress assessment and CO_2/climate connection. Water Resour. Res. 22: 1702.

Idso, S.B., R.D. Jackson, P.J. Pinter, R.J. Reginato, and J.L. Hatfield. 1981a. Normalizing the stress degree day for environmental variability. Agric. Meteorol. 24(1): 45-55.

Idso, S.B., R.J. Reginato, J.L. Hatfield, G.K. Walker, R.D. Jackson, and P.J. pinter. 1980. A generalization of the stress degree day concept of yield prediction to accommodate a diversity of crops. Agric. Meteorol. 21: 205-211.

Idso, S.B., R.J. Reginato, R.P. Jackson, and P.J. Pinter. 1981b. Meaauring yield-reducing plant water potential depressions in wheat by infrared thermometry remote sensing of plant water stress. Irrig. Sci. 2(4): 205-211.

Idso, S.B., R.J. Reginato, D.C. Reicosky, and J.C. Hatfield. 1981c. Determining soil induced plant water potential depressions in alfalfa by means of infrared thermometry. Agron. J. 73: 826-830.

Jackson, R.D. 1982. Canopy temperature and crop water stress. In Advances in Irrigation, ed. D. Hillel, 1:43-85. New York: Academic Press.

Jackson, R.D. 1988. A reexamination of the crop water stress index. Irrig. Sci. 9: 309-317.

Jones, J.W. 1985. Using expert systems in agicultural models. Agricultural Engineering 66(7): 21-23.

Kumar, D., T.A> Dillaha, L.D. Heatwole, and B.B. Ross. 1989. Aknowledge based system for irrigation planning in Virginia. ASAE Paper No. 89-7520, ASAE, St. Joseph, MI 49085.

Lemmon, H. 1986. COMAX: an expert system for cotton crop management. Science 233: 29-33.

Levin, I. and E. Schmueli. 1964. The response of cotton to various irrigation regimes in the Hula Valley. Isreal J. of Agric. Res. 14: 211-225.

Luger, G.F. and W.A. Stubblefield. 1989. Artificial intelligence and the design of expert systems. Cummings, calif.: Benjamin.

Martin, D.L., E.C. Stegman, and E. Fereres. 1990. Irrigation scheduling principles. In Management of Farm Irrigation Systems. ASAE monograph: 155-201.

McKinion, J.M. and H.E. Lemmon. 1985. Expert systems for agriculture. Computers and Electronics in Agriculture 1: 31-34.

Miller, A. 1986. Expert systems: the structure, history, and future of successful AI application. IEEE potentials, October.

Miller, B.D. and O.T. Denmead. 1976. Water relations of wheat leaves in the field. Agron. J. 68: 303-307.

Pair, C.H., W.H. Hinz, K.R. Frost, R.E. Sneed, and T.J. Schiltz (Eds.). 1983. Irrigation. The Irrigation Association, Silver Spring Md.

Palmer, R.G. 1986. How expert system can improve crop production. Agricultural Engineering 67(6): 28-29.

Parsaye, K. and M. Chignell. 1988. Expert system for experts. John Wley and Sons, Inc.

Plant. R.E., L.T. Wilson, L.Zelinski, P.B. Goodell, and T.A. Kerby. 1987. CALEX/Cotton: an expert system based management aid for califormia cotton growers. Proceeding Beltwide Cotton Production Research Conference, 1987.

Richer, M, 1986. An evaluation of expert system development tools. Expert Systems 3(3): 166-183.

Ritchie, G.A. and T.M. Hinckley. 1975. The pressure chamber as an instrument for ecological research. Adv. Ecol. Res. 9: 165-254.

Stanberry, C.O., et al. 1963. Sweet corn production as affected by moisture and nitrogen variables. Agron. J. 55: 159-161.

Stegman, E.C. 1983. Corn and sunflower yield vs. management of leaf xylem presseures. Transactions of the ASAE. 26(5): 1362-1368, 1374.

Stegman, E.C. 1989. Soybean yields as influenced by timing of Et deficits. Transactions of the ASAE. 32(2): 551-557.

Stegman, E.C. and D.C. Nelson. 1973. Potato response to moisture regimes. ND RES. Ept. No. 44, Agr. Sta., ND State Univ., Gargo, ND.

Stegman, E.C., L.H. Schiele, and A. Bauer. 1976. Plant water stress critria for irrigation scheduling. Transactions of the ASAE. 19(5): 850-855.

Stone, N.D., R.N. Coulson, R.E. Frisbie, and D.K. Loh. 1986a. Expert systems in entomology: three approaches to problem solving. Bullition of the Entomological Society of America 32: 161-166.

Stone, N.D., R.E. Frisbie, J.W. Richardson, and R.N. Coulson. 1986b. Integrated expert system applications for agriculture. Pro. International Conference on Computers in Agricultural Extension Programs (in Press).

Swancy, D.P., J.W. Jones, W.G. Boggess, G.G. Wilkerson, and J.W. Mishoe. 1983. Real-time irrigation decision analysis using simulation. Transactions of ASAE 26(2): 562-568.

Taylor, S.A. 1965. Managing irrigation water on the farm. Transactions of the ASAE 8(3): 433-435.

Turner, N.C. 1988. Measurement of plant water status by the pressure chamber technique. Irrig. Sci. 9: 289-308.

Vittum, M.T., et al. 1963. Crop response to irrigation in the Northeast. Bulletin 800, New York Agric. Exp. Sta., Geneva, Switzerland.

Waterman, D.A. 1986. A guide to expert system. Addison-Wesley, Reading, Massachusetts.

Whitt, D.M. 1954. Effects of supplemental water on field crops. Bulletin 616, Missouri Agric. Exp. Sta.

APPENDICES

APPENDIX A

BASIC EXPERT SYSTEM TERMINOLOGY

Basic Expert System Terminology

Term	***Meaning***
Artificial Intelligence	The part of computer science concerned with developing intelligent computer programs.
Domain expert	A person who through years of training and experience has become extremely proficient at problem solving in a particular domain.
End-user	The person who uses the finished expert system; the person for whom the system was developed.
Expert system	A computer program using expert knowledge to attain high levels of performance in a narrow problem area.
Expert-system-building tool	The programming language and support package used to build the expert system.
Knowledge engineering	The processing of building expert systems.
Knowledge engineer	The person who designs and builds the expert system.
Representation	The process of Formulating or viewing a problem so it will by easy to solve.
Tool builder	The person who designs and builds the expert-system-building tool.
User	A person who uses an expert system, such as end-user, a domain expert, a knowledge engineer, a tool builder, or a clerical staff member.
Certainty factor	A number that measures the certainty or confidence one has that a fact or rule is valid.
Frame	A knowledge representation method that associates features with nodes representing concepts or objects. The features are described in terms of attributes (called slots) and their values.
Heuristic	A rule of thumb or simplification that limits the search for solutions in domains that are difficult and poorly understood.
Inference engine	That part of a knowledge-based system or expert system that contains the general problem-solving knowledge.

Basic Expert System Terminology	
Backward chaining	An inference method where the system starts with what it wants to prove, e.g., Z, and tries to establish the facts it needs to prove Z.
Forward chaining	An inference method where rules are matched against facts to establish new facts.
knowledge	The information a computer program must have to behave intelligently.
Knowledge representation	The process of structuring knowledge about a problem in a way that makes the problem easier to solve.
Knowledge-based system	A program in which the domain knowledge is explicit and separate from the program's other knowledge.
Knowledge base	The portion of a knowledge-based system or expert system that contains the domain knowledge.
Rule-based methods	Programming methods using IF-THEN rules to perform forward or backward chaining.
Rule	A formal way of specifying a recommendation, directive, or strategy, expressed as IF premise THEN conclusion or IF condition THEN action.

APPENDIX B

CROP MANAGEMENT EXPERT KNOWLEDGE BASE

title($ Crop Management Expert (Ver 0.1) $).

initialscreen($

CROP

MANAGEMENT

EXPERT

SYSTEM

This system assists in determining irrigation, fertilization,
and pest strategies

Brought to you by

OREGON STATE UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

EXTENSION SERVICE

Version 0.1 $).

information($

This expert system provides advice on managing and scheduling irrigation and fertilizer applications for wheat production in the Columbia Basin.

CMX was developed at Oregon State University.
$).

```
goal( recommendation(_)).


/*
-----------------------------
askable facts
-----------------------------
*/

askable( get_option(_)).
askable( get_method(_)).
askable( get_choice(_)).
askable( crop_type(_)).
askable( crop_growth_stage(_)).
askable( soil_type(_)).
askable( actual_Et_rate_in(_)).
askable( actual_Et_rate_mm(_)).
askable( last_irrigation(_)).
askable( rainfall_in(_)).
askable( rainfall_mm(_)).
askable( soil_moisture_depletion(_)).
askable( allowable_depletion(_)).
askable( irrigation_efficiency(_)).
askable( irrigation_strategy(_)).
askable( rain_chance(_)).
askable( cwsi_value(_)).
askable( lwp_value_bar(_)).
askable( lwp_value_mp(_)).
askable( swp_value_bar(_)).
askable( swp_value_kp(_)).
askable( placement_option(_)).
askable( wheat_type(_)).
askable( geographical_area(_)).
askable( nitrogen_data(_)).
askable( phosphorus_data(_)).
askable( potassium_data(_)).
askable( nitrogen_concentration(_)).
askable( phosphorus_concentration(_)).
askable( potassium_concentration(_)).
askable( yield_goal(_)).
askable( fertilizer_requirement(_)).
askable( nitrogen_deficiency(_)).
askable( phosphorus_deficiency(_)).
askable( potassium_deficiency(_)).
askable( high_protein(_)).
```

```
askable( water_deficit(_)).
askable( critical_stage(_)).
askable( specific_data(_)).
askable( cropGrowthStage(_)).
askable( soilMoistureLevel(_)).
askable( cropAppearance(_)).
askable( soilTexture(_)).
askable( units(_)).

/*
-----------------------------
numeric declarations
-----------------------------
*/

numeric( allowable_depletion(_), integer, 50).
numeric( actual_Et_rate_in(_), real, 0.0).
numeric( actual_Et_rate_mm(_), real, 0.0).
numeric( last_irrigation(_), integer, 0).
numeric( rainfall_mm(_), integer, 0).
numeric( rainfall_in(_), real, 0).
numeric( irrigation_efficiency(_), integer, 75).
numeric( cwsi_value(_), real, 0.3).
numeric( lwp_value_bar(_), real, 10.0).
numeric( lwp_value_mp(_), real, 1.0).
numeric( swp_value_kp(_), integer, 80).
numeric( swp_value_bar(_), real, 0.8).
numeric( yield_goal(_), integer, 100).
numeric( nitrogen_concentration(_), integer, 0).
numeric( phosphorus_concentration(_), integer, 0).
numeric( potassium_concentration(_), integer, 0).

/*
-----------------------------
menu choices
-----------------------------
*/

choices( get_option(_), [ 'Irrigation Management', 'Fertilization Management','Pest
        Management' ]).
choices( get_method(_), [ 'Management Allowed Depletion', 'Soil Water Potential', 'Leaf Water
        Potential', 'Water Stress Indices' ]).
choices( get_choice(_), [ 'Crop Water Stress Index', 'Stress Day Index' ]).
choices( crop_type(_), [ wheat, alfalfa, soybean, cotton, maize, potato ]).
choices( crop_growth_stage(_),[ preplanting, planting, tillering, booting, heading, flowering,
        ripening, harvest]).
choices( soil_type(_), [ sand, 'loamy sand', 'sandy loam', 'silt loam',          'clay loam', clay]).
choices( soil_moisture_depletion(_),[ yes, no ]).
choices( irrigation_strategy(_),[ 'Full Irrigation', 'Deficit Irrigation' ]).
choices( rain_chance(_), [ 'less than 60', 'great than 60' ]).
choices( placement_option(_), [ 'banded with seed', 'banded beside seed', 'banded under
```

```
        seed', topdressing ]).
choices( wheat_type(_), [ 'Winter Wheat', 'Spring Wheat' ]).
choices( geographical_area(_), [ 'arid area', 'semiarid area', 'subhumid area', 'humid area' ]).
choices( fertilizer_requirement(_), [ nitrogen, phosphorus, potassium ]).
choices( nitrogen_data(_), [ yes, no ]).
choices( phosphorus_data(_), [ yes, no ]).
choices( potassium_data(_), [ yes, no ]).
choices( nitrogen_deficiency(_), [ yes, no ]).
choices( phosphorus_deficiency(_), [ yes, no ]).
choices( potassium_deficiency(_),[ yes, no ]).
choices( high_protein(_), [ yes, no ]).
choices( water_deficit(_), [ yes, no ]).
choices( critical_stage(_), [ yes, no ]).
choices( specific_data(_), [ yes, no ]).
choices( cropGrowthStage(_), [ early, mid, late, harvest ]).
choices( soilMoistureLevel(_), [ wet, moist, medium, dry ]).
choices( cropAppearance(_), [ ok, 'under stress' ]).
choices( soilTexture(_), [ fine, coarse ]).
choices( units(_), [ english, metric ]).

/*
-----------------------------
help text
-----------------------------
*/
help(_, $
        You are requested to make a selection of the menu presented.

        To select an item of the menu, use the cursor (arrow) keys
on the right side of your keyboard. If you are using the
cursor keys on the numeric keypad, you must have the <NumLock>
key turned ON (usually indicated by a light in the upper right
-hand corner of the keyboard.

        You may use the <Home> or <PageUP> keys to move to the end of
a menu. As you move, you current location on the menu will
be highlighted. When you have highlighted your desired
selection, hit the <Enter> key to select your choice.
$).

/*
-----------------------------
prompts
-----------------------------
*/

prompt( get_option(_), $
        Which option do you wish to pursue?
        This system mainly provides recommendations on irrigation management and
fertilization management.
(Note: So far pest management section has not been developed)
```

$).
prompt(specific_data(_), $
Do you have any specific data which can be used to make the irrigation decision?
I will use some irrigation timing criteria such as Management Allowed Depletion(MAD), Soil Water Potential(SWP), Leaf Water Potential(LWP), and Crop Water Stress Index(CWSI) to schedule irrigation for you. If you have some specific data for these timing criteria, you can just answer "yes". Otherwise, you may answer "no".
$).
prompt(get_method(_), $
Based on the specific data, which method do you prefer to use?
There are several methods which can be used to predict when to irrgate.
$).
prompt(get_choice(_),$
In the water stress indices, there are two indices, e.g., crop water stress index and stress day index. which do you want to use?
$).
prompt(cropGrowthStage(_), $
What is the crop growth stage? (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity.)
$).
prompt(soilMoistureLevel(_), $
What is the soil moisture level? (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry is ≤ 35%.)
$).
prompt(cropAppearance(_), $
Does the crop look OK or under stress? (ok means that the crop looks healthy; under stress means that it is showing signs of moisture stress.)
$).
prompt(soilTexture(_), $
What is the soil texture? (fine is clay loam to clay; coarse is sandy to sandy loam.)
$).
prompt(crop_type(_),$
What kind of crop do you have?
In general, the different crop has the different water and nutrient requirement.
$).
prompt(soil_type(_),$
What is the soil type?
The soil type influences the soil water holding capacity and the nutrient movement.
$).
prompt(crop_growth_stage(_),$
What is the crop growth stage?
For irrigation and fertilizer scheduling, the crop growth stage is very important. Because if there is not enough water and nutrient in critical growth stage, the yield will be reduced significantly.
$).
prompt(allowable_depletion(_),$
What is the allowable depletion(%)?
Management Allowed Depletions(MAD) are the most used criteria for irrigation timing, particularly for water balance methods of irrigation scheduling. These criteria express the proportion or percentage of the root zone "plant available or extractable" water storage capacity that can be depleted between irrigations for maintenance of a nonstress or low stress

environment for crop growth.
$).
prompt(actual_Et_rate_in(_),$
What is the actual evapotranspiration rate(inch/day) since the last irrigation?
You can estimate evapotranspiration for each day using observed climatic data.
$).
prompt(actual_Et_rate_mm(_),$
What is the actual evapotranspiration rate(mm/day) since the last irrigation?
You can estimate evapotranspiration for each day using observed climatic data.
$).
prompt(last_irrigation(_),$
How many days since the last irrigation?
$).
prompt(rainfall_mm(_),$
what is the total rainfall since the last irrigation (mm)?
$).
prompt(rainfall_in(_),$
what is the total rainfall since the last irrigation (in)?
$).
prompt(irrigation_efficiency(_),$
What is the irrigation efficiency(%) of your irrigation system? You are requested to input the percentage of irrigation efficiency.If you do not know the exact value for the irrigation efficiency, you may refer the following data.

Type of System	Application Efficiency Range,%
Furrow	40-85
Hand Move	60-85
Solid Set	60-85
Boom	55-75
Traveler	55-75
Center Pivot	75-90
Linear Move	70-90

$).
prompt(soil_moisture_depletion(_),$
In order to get the irrigation advice, we need to know the soil moisture depletion. would you please give me the following information(for example, rainfall,actual ET rate,etc.)?
$).
prompt(irrigation_strategy(_),$
Which kind of irrigation strategy do you want to use?
Generally, there are two strategies,e.g., full irrigation and deficit irrigation. Full irrigation is to prevent crop water stress throughout the growing season. Deficit irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction. Management of deficit irrigation is fundamentally very different from conventional irrigation management. The potential benefits of deficit irrigation derive from three factors: reduced costs of production, greater irrigation water use efficiency and the opportunity costs of water.
$).
prompt(rain_chance(_), $

```
        What is the possibility (%) of rain with the next 2 days?
$).
prompt( cwsi_value(_), $
        Please input the crop water stress index?
        A crop water stress index(CWSI) has been defined as:
                CWSI = 1 - Et/Etp
        where :
        Et/Etp = the ratio of actual to potential evapotranspiration rate. This ratio ranges from
1 (ample water) to zero (no available water). CWSI varies from a value of zero for no water
stress to a maximum value of one at severe stress.
$).
prompt( lwp_value_mp(_),$
        What is the plant leaf water potential (MPa)? (note: just skip the minus sign.)
        Leaf water potentials can be measured with commercially available pressure
chambers. Because time of day is an important consideration with this technique,
measurements of leaf water potentials for irrigation timing are most suited to research
applications.
$).
prompt( lwp_value_bar(_),$
        What is the plant leaf water potential (bar)? (note: just skip the minus sign.)
        Leaf water potentials can be measured with commercially available pressure
chambers. Because time of day is an important consideration with this technique,
measurements of leaf water potentials for irrigation timing are most suited to research
applications.
$).
prompt( swp_value_kp(_),$
        What is the soil water potential (kPa)? (note: just skip the minus sign.)
        Soil water potential can be sensed during freeze free periods with tensiometers.
Certain relationships between soil matric potential and available water depletion exists.
$).
prompt( swp_value_bar(_),$
        What is the soil water potential (bar)? (note: just skip the minus sign.)
        Soil water potential can be sensed during freeze free periods with tensiometers.
Certain relationships between soil matric potential and available water depletion exists.
$).
prompt( placement_option(_),$
        Which kind of application method do you prefer to use?
$).
prompt( wheat_type(_),$
        Are you using winter or spring wheat?
$).
prompt( geographical_area(_),$
        What best describes your geographical area.
$).
prompt( nitrogen_data(_), $
        Do you know the soil nitrogen concentration from the soil test?
$).
prompt( phosphorus_data(_), $
        Do you know the soil phosphorus concentration from the soil test?
$).
prompt( potassium_data(_), $
```

```
        Do you know the soil potassium concentration from the soil test?
$).
prompt( nitrogen_deficiency(_), $
        Do wheat plants become light green and then yellow?
        ( This symptom starts with the oldest leaves and progresses to the youngest leaves.
Odler leaves eventually turn brown and die while the limited     supplies are allocated by the
plant to the newest growth.)
$).
prompt( phosphorus_deficiency(_), $
        Wheat plants are stunted and poorly tillered, the stems are slender and poorly rooted,
the leaves are smaller and darker green than normal, and    plant maturity is delayed. Is there
one of above symptioms in you wheat plants?
$).
prompt( potassium_deficiency(_), $
        Are there following symptoms in potassium?
        Wheat plants tend to be short and have weak stems, owing to their short and spindly
internodes. In addition, the leaves turn yellow and then dry up,     starting with the tips and
then the margins of the older leaves, and the tiller roots fail to develop, or they appear but not
extend as aggressively into the soil as healthy roots do.
$).
prompt( nitrogen_concentration(_), $
        What is the concentration of nitrogen in the soil now (pounds/acre)?
$).
prompt( phosphorus_concentration(_),$
        What is the concentration of phosphorus in the soil now (pounds/acre)?
$).
prompt( potassium_concentration(_),$
        What is the concentration of potassium in the soil now (pounds/acre)?
$).
prompt( yield_goal(_),$
        What is your yield goal(attainable yield)( bushel/acre )?
$).
prompt( fertilizer_requirement(_),$
        At first, in order to know the total requirement of specific nutrient, you need to choose
one.
$).
prompt( high_protein(_),$
        Are you especially interested in high grain protein?
$).
prompt( water_deficit(_),$
        Is soil water defict greater than optimal depletion?
$).
prompt( critical_stage(_), $
        Is your crop in the critical growth stage?
$).
prompt( units(_), $
        Do you want to use english or metric units?
$).


/*
```

```
-----------------------------
          Rules
-----------------------------
*/

/*
-----------------------------
rules for: crop management
-----------------------------
*/

rule   /*  for irrigation scheduling */
if   get_option( 'Irrigation Management' )
then is( irrigation_scheduling )
and  text( irrigation_scheduling ).

rule   /*  for fertilization management */
if   get_option( 'Fertilization Management' )
then is( 'Fertilization Management' )
and  text( 'Fertilization Management' ).

rule   /* for pest management */
if   get_option( 'Pest Management' )
then recommendation( 'Pest Management' )
and  text( 'Pest Management' ).


/*
____________________________________________
rules for: irrigation strategy
____________________________________________
*/


rule    /* determining full irrigation using MAD */
if      is( irrigation_scheduling )
and     irrigation_strategy( 'Full Irrigation' )
and     specific_data( yes )
and     get_method( 'Management Allowed Depletion' )
then    fullIrrigation( FullIrrigationMAD )
and     text( fi_mad ).

rule    /* determining full irrigation using MAD */
if      is( irrigation_scheduling )
and     irrigation_strategy( 'Full Irrigation' )
and     specific_data( no )
then    tryDifferentWay( try_some_other_way )
and     text( try_some_other_way ).

rule    /* determining deficit irrigation using MAD */
if      is( irrigation_scheduling )
```

```
and     irrigation_strategy( 'Deficit Irrigation' )
and     get_method( 'Management Allowed Depletion' )
then    recommendation( DeficitIrrigationMAD )
and     text( di_mad ).

rule    /* determining full irrigation using SWP */
if      is( irrigation_scheduling )
and     irrigation_strategy( 'Full Irrigation' )
and     specific_data( yes )
and     get_method( 'Soil Water Potential' )
then    method_swp( IrrigationSWP )
and     text( fi_swp ).

rule    /* determining full irrigation using LWP */
if      is( irrigation_scheduling )
and     irrigation_strategy( 'Full Irrigation' )
and     specific_data( yes )
and     get_method( 'Leaf Water Potential' )
then    method_lwp( FullIrrigationLWP )
and     text( fi_lwp ).

rule    /* determining full irrigation using WSI */
if      is( irrigation_scheduling )
and     irrigation_strategy( 'Full Irrigation' )
and     specific_data( yes )
and     get_method( 'Water Stress Indices' )
then    wsi( fiwsi )
and     text( fi_wsi).

rule    /* determining full irrigation using SDI */
if      wsi( fiwsi )
and     get_choice( 'Stress Day Index' )
then    recommendation( fisdi )
and     text( sdi ).

rule    /* choosing  one of methods in water stress indices */
if      wsi( fiwsi )
and     get_choice( 'Crop Water Stress Index' )
then    method_is( ficwsi )
and     text( cwsi ).

rule    /* determining deficit irrigation using WSI */
if      is( irrigation_scheduling )
and     irrigation_strategy( 'Deficit Irrigation' )
and     get_method( 'Water Stress Indices' )
then    wsi( diwsi )
and     text( di_wsi ).

rule    /* determining deficit irrigation using CWSI */
if      wsi( diwsi )
and     get_choice( 'Crop Water Stress Index' )
```

```
then    recommendation( dicwsi )
and     text( cwsi ).

rule    /* determining deficit irrigation using SDI */
if      wsi( diwsi )
and     get_choice( 'Stress Day Index' )
then    recommendation( disdi )
and     text( sdi ).

rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( early )
or      cropGrowthStage( mid )
or      cropGrowthStage( late )
and     soilMoistureLevel( wet )
then    recommendation( no_irrigation_anymore)
and     text( no_water ).

rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( early )
or      cropGrowthStage( mid )
or      cropGrowthStage( late )
and     soilMoistureLevel( dry )
then    recommendation( irrigation_now_d)
and     text( need_water ).

rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( early )
or      cropGrowthStage( mid )
and     soilMoistureLevel( moist )
then    recommendation( no_irrigation_m )
and     text( no_water ).

rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( late )
and     soilMoistureLevel( moist )
and     soilTexture( fine )
then    recommendation( no_irrigation_f )
and     text( no_water ).

rule  /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( late )
and     soilMoistureLevel( moist )
and     soilTexture( coarse )
then    recommendation( irrigation_c )
and     text( need_water ).
```

```
rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( early )
or      cropGrowthStage( mid )
or      cropGrowthStage( late )
and     soilMoistureLevel( medium )
and     cropAppearance( ok )
and     soilTexture( fine )
then    recommendation( no_irrigation_of)
and     text( no_water ).

rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( early )
or      cropGrowthStage( mid )
or      cropGrowthStage( late )
and     soilMoistureLevel( medium )
and     cropAppearance( ok )
and     soilTexture( coarse )
then    recommendation( irrigation_oc)
and     text( need_water ).

rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( early )
or      cropGrowthStage( mid )
or      cropGrowthStage( late )
and     soilMoistureLevel( medium )
and     cropAppearance( 'under stress' )
then    recommendation( irrigation_w)
and     text( need_water ).

rule    /* using general information to generate the irrigation decision */
if      tryDifferentWay( try_some_other_way)
and     cropGrowthStage( harvest )
then    recommendation( no_irrigation_h)
and     text( noIrrigation).


/*
____________________________________________________

rules for: making irrigation decision using CWSI
____________________________________________________

*/

rule    /* Using CWSI to make irrigation decision for wheat
if      method_is( ficwsi )
and     crop_type( wheat )
and     cwsi_value( CWSIValue )
and     CWSIValue < 0.3
then    recommendation( no_water )
```

```
and     text( no_water ).

rule    /* Using CWSI to make irrigation decision for wheat */
if      method_is( ficwsi )
and     crop_type( wheat )
and     cwsi_value( CWSIValue )
and     CWSIValue >= 0.3
and     CWSIValue =< 0.5
and     crop_growth_stage( preplanting )
or      crop_growth_stage( planting )
then    recommendation( just_waiting )
and     text( aow_1 ).

rule    /* Using CWSI to make irrigation decision for wheat */
if      method_is( ficwsi )
and     crop_type( wheat )
and     cwsi_value( CWSIValue )
and     CWSIValue >= 0.3
and     CWSIValue =< 0.5
and     crop_growth_stage( tillering )
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
then    recommendation( water_cwsi )
and     text( water_critical_stage ).

rule    /* Using CWSI to make irrigation decision for wheat */
if      method_is( ficwsi )
and     crop_type( wheat )
and     cwsi_value( CWSIValue )
and     CWSIValue > 0.5
then    recommendation( addwaternow )
and     text( add_water_now ).

rule    /* no irrigation needed */
if      method_is( ficwsi )
and     crop_type( wheat )
and     cwsi_value( CWSIValue )
and     crop_growth_stage( harvest )
or      crop_growth_stage( ripening )
then    recommendation( no_water_cwsi )
and     text( noIrrigation ).


/*
_______________________________________________
rules for: making irrigation decision using SWP
_______________________________________________
*/

rule    /* Using SWP to make irrigation decision for wheat */
```

```
if      method_swp( IrrigationSWP )
and     crop_type( wheat )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
and     SWPValue < 80
then    recommendation( nowater_w_1 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for wheat */
if      method_swp( IrrigationSWP )
and     crop_type( wheat )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
and     SWPValue >= 80
and     SWPValue =< 90
and     critical_stage( yes )
then    recommendation( water_wheat )
and     text( water_critical_stage ).

rule    /* Using SWP to make irrigation decision for wheat */
if      method_swp( IrrigationSWP )
and     crop_type( wheat )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
and     SWPValue >= 80
and     SWPValue =< 90
and     critical_stage( no )
then    recommendation( waiting_swp_w )
and     text( waiting_swp_crop).

rule    /* Using SWP to make irrigation decision for wheat */
if      method_swp( IrrigationSWP )
and     crop_type( wheat )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
and     SWPValue > 90
then    recommendation( supplywaternow_1 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for wheat */
if      method_swp( IrrigationSWP )
and     crop_type( wheat )
and     soil_type( 'clay loam' )    % clay loam
and     swp_value( SWPValue )
and     SWPValue >= 140
then    recommendation( supplywaternow_2 )
and     text( need_water ).

rule    /* Using SWP to make irrigation decision for wheat */
if      method_swp( IrrigationSWP )
and     crop_type( wheat )
```

```
and     soil_type( 'clay loam' )    % clay loam
and     swp_value( SWPValue )
and     SWPValue < 140
then    recommendation( nowater_w_2 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for cotton */
if      method_swp( IrrigationSWP )
and     crop_type( cotton )
and     soil_type( 'clay loam' )    % clay loam
and     swp_value( SWPValue )
and     SWPValue >= 150
then    recommendation( addwaternow_c_2 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for cotton */
if      method_swp( IrrigationSWP )
and     crop_type( cotton )
and     soil_type( 'clay loam' )    % clay loam
and     swp_value( SWPValue )
and     SWPValue < 150
then    recommendation( nowater_c_2 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for cotton */
if      method_swp( IrrigationSWP )
and     crop_type( cotton )
and     soil_type( 'silt loam' )    % silt loam
and     swp_value( SWPValue )
and     SWPValue < 100
then    recommendation( nowater_c_3 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for cotton */
if      method_swp( IrrigationSWP )
and     crop_type( cotton )
and     soil_type( 'silt loam' )    % silt loam
and     swp_value( SWPValue )
and     SWPValue >= 100
then    recommendation( addwaternow_c_3 )
and     text( need_water ).

rule    /* Using SWP to make irrigation decision for alfalfa */
if      method_swp( IrrigationSWP )
and     crop_type( alfalfa )
and     soil_type( 'loamy sand' )          % loamy sand
and     swp_value( SWPValue )
and     SWPValue < 50
then    recommendation( notwater_a_1 )
and     text( no_water ).
```

```
rule    /* Using SWP to make irrigation decision for alfalfa */
if      method_swp( IrrigationSWP )
and     crop_type( alfalfa )
and     soil_type( 'loamy sand' )           % loamy sand
and     swp_value( SWPValue )
and     SWPValue >= 50
then    recommendation( addwater_a_1 )
and     text( need_water ).

rule    /* Using SWP to make irrigation decision for alfalfa */
if      method_swp( IrrigationSWP )
and     crop_type( alfalfa )
and     soil_type( 'sandy loam' )           % sandy loam
and     swp_value( SWPValue )
and     SWPValue < 80
then    recommendation( notwater_a_3 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for alfalfa */
if      method_swp( IrrigationSWP )
and     crop_type( alfalfa )
and     soil_type( 'sandy loam' )           % sandy loam
and     swp_value( SWPValue )
and     SWPValue >= 80
then    recommendation( addwater_a_3 )
and     text( need_water ).

rule    /* Using SWP to make irrigation decision for alfalfa */
if      method_swp( IrrigationSWP )
and     crop_type( alfalfa )
and     soil_type( 'clay loam' )    % clay loam
and     swp_value( SWPValue )
and     SWPValue >= 150
then    recommendation( addwater_a_4 )
and     text( need_water ).

rule    /* Using SWP to make irrigation decision for alfalfa */
if      method_swp( IrrigationSWP )
and     crop_type( alfalfa )
and     soil_type( 'clay loam' )    % clay loam
and     swp_value( SWPValue )
and     SWPValue < 150
then    recommendation( nowater_a_4 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'sandy loam' )           % sandy loam
and     swp_value( SWPValue )
and     SWPValue >= 80
```

```
then    recommendation( addwaternow_m_1 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
and     SWPValue < 80
then    recommendation( nowaternow_m_1 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'clay loam' )     % clay loam
and     swp_value( SWPValue )
and     SWPValue >= 130
then    recommendation( addwaternow_m_2 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'clay loam' )     % clay loam
and     swp_value( SWPValue )
and     SWPValue < 130
then    recommendation( nowaternow_m_2 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'sand' )          % sand
and     swp_value( SWPValue )
and     SWPValue < 20
then    recommendation( nowaternow_m_2 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'sand' )          % sand
and     swp_value( SWPValue )
and     SWPValue >= 20
then    recommendation( addwaternow_m_2 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
```

```
and     soil_type( 'silt loam' )       % silt loam
and     swp_value( SWPValue )
and     SWPValue > 200
then    recommendation( addwaternow_m_2 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'silt loam' )       % silt loam
and     swp_value( SWPValue )
and     SWPValue < 75
then    recommendation( nowaternow_m_2 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'silt loam' )       % silt loam
and     swp_value( SWPValue )
and     swp_value >= 75
and     swp_value =< 200
and     critical_stage( yes )
then    recommendation( water_maize_swp )
and     text( water_critical_stage_m ).

rule    /* Using SWP to make irrigation decision for maize */
if      method_swp( IrrigationSWP )
and     crop_type( maize )
and     soil_type( 'silt loam' )       % silt loam
and     swp_value( SWPValue )
and     swp_value >= 75
and     swp_value =< 200
and     critical_stage( no )
then    recommendation( waiting_maize_swp )
and     text( waiting_swp_crop ).

rule    /* Using SWP to make irrigation decision for soybean */
if      method_swp( IrrigationSWP )
and     crop_type( soybean )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
and     SWPValue >= 50
then    recommendation( addwaternow_s_1 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for soybean */
if      method_swp( IrrigationSWP )
and     crop_type( soybean )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
```

```
and     SWPValue < 50
then    recommendation( nowaternow_s_1 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for soybean */
if      method_swp( IrrigationSWP )
and     crop_type( soybean )
and     soil_type( 'silt loam' )      % silt loam
and     swp_value( SWPValue )
and     SWPValue >= 150
then    recommendation( addwaternow_s_2 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for soybean */
if      method_swp( IrrigationSWP )
and     crop_type( soybean )
and     soil_type( 'silt loam' )      % silt loam
and     swp_value( SWPValue )
and     SWPValue < 150
then    recommendation( nowaternow_s_2 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'silt loam' )      % silt loam
and     swp_value( SWPValue )
and     SWPValue >= 50
then    recommendation( addwaternow_p_1 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'silt loam' )      % silt loam
and     swp_value( SWPValue )
and     SWPValue < 50
then    recommendation( nowaternow_p_1 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'loamy sand' )           % loamy sand
and     swp_value( SWPValue )
and     SWPValue >= 40
then    recommendation( addwaternow_p_2 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
```

```
and     crop_type( potato )
and     soil_type( 'loamy sand' )         % sand
and     swp_value( SWPValue )
and     SWPValue < 40
then    recommendation( nowaternow_p_2 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'clay loam' )          % clay loam
and     swp_value( SWPValue )
and     SWPValue > 80
then    recommendation( addwaternow_p_3 )
and     text( add_water_now ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'clay loam' )          % clay loam
and     swp_value( SWPValue )
and     SWPValue < 60
then    recommendation( nowaternow_p_3 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'clay loam' )          % clay loam
and     swp_value( SWPValue )
and     SWPValue >= 60
and     SWPValue =< 80
and     critical_stage( yes )
then    recommendation( addwater_p_3 )
and     text( water_critical_stage_p ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'clay loam' )          % clay loam
and     swp_value( SWPValue )
and     SWPValue >= 60
and     SWPValue =< 80
and     critical_stage( no )
then    recommendation( waiting_swp_p )
and     text( waiting_swp_crop ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'sandy loam' )         % sandy loam
```

```
and     swp_value( SWPValue )
and     SWPValue < 50
then    recommendation( nowaternow_p_4 )
and     text( no_water ).

rule    /* Using SWP to make irrigation decision for potato */
if      method_swp( IrrigationSWP )
and     crop_type( potato )
and     soil_type( 'sandy loam' )          % sandy loam
and     swp_value( SWPValue )
and     SWPValue >=50
then    recommendation( addwaternow_p_4 )
and     text( add_water_now ).


/*
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rules for: making irrigation decision using LWP
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*/

rule    /* Using LWP to make irrigation decision for wheat */
if      method_lwp( FullIrrigationLWP )
and     crop_type( wheat )
and     lwp_value( LWPValue )
and     LWPValue < 1.4
then    recommendation( water_not_w )
and     text( no_water ).

rule    /* Using LWP to make irrigation decision for wheat */
if      method_lwp( FullIrrigationLWP )
and     crop_type( wheat )
and     lwp_value( LWPValue )
and     LWPValue > 1.9
then    recommendation( add_water_w )
and     text( add_water_now ).

rule    /* Using LWP to make irrigation decision for wheat */
if      method_lwp( FullIrrigationLWP )
and     crop_type( wheat )
and     lwp_value( LWPValue )
and     LWPValue =< 1.9
and     LWPValue >= 1.4
and     critical_stage( no )
then    recommendation( water_w )
and     text( waiting_lwp_w ).

rule    /* Using LWP to make irrigation decision for wheat */
if      method_lwp( FullIrrigationLWP )
and     crop_type( wheat )
```

```
and     lwp_value( LWPValue )
and     LWPValue =< 1.9
and     LWPValue >= 1.4
and     critical_stage( yes )
then    recommendation( water_critical_stage_w )
and     text( water_critical_stage ).

rule    /* Using LWP to make irrigation decision for alfalfa */
if      method_lwp( FullIrrigationLWP )
and     crop_type( alfalfa )
and     lwp_value( LWPValue )
and     LWPValue < 1.0
then    recommendation( water_not_a )
and     text( no_water ).

rule    /* Using LWP to make irrigation decision for alfalfa */
if      method_lwp( FullIrrigationLWP )
and     crop_type( alfalfa )
and     lwp_value( LWPValue )
and     LWPValue > 1.3
then    recommendation( add_water_a )
and     text( add_water_now ).

rule    /* Using LWP to make irrigation decision for alfalfa */
if      method_lwp( FullIrrigationLWP )
and     crop_type( alfalfa )
and     lwp_value( LWPValue )
and     LWPValue =< 1.3
and     LWPValue >= 1.0
and     critical_stage( yes )
then    recommendation( water_a )
and     text( water_critical_stage_a ).

rule    /* Using LWP to make irrigation decision for alfalfa */
if      method_lwp( FullIrrigationLWP )
and     crop_type( alfalfa )
and     lwp_value( LWPValue )
and     LWPValue =< 1.3
and     LWPValue >= 1.0
and     critical_stage( no )
then    recommendation( waiting_crop_a )
and     text( waiting_lwp_crop ).

rule    /* Using LWP to make irrigation decision for cotton */
if      method_lwp( FullIrrigationLWP )
and     crop_type( cotton )
and     lwp_value( LWPValue )
and     LWPValue < 1.2
then    recommendation( water_not_c )
and     text( no_water ).
```

```
rule    /* Using LWP to make irrigation decision for cotton */
if      method_lwp( FullIrrigationLWP )
and     crop_type( cotton )
and     lwp_value( LWPValue )
and     LWPValue > 1.5
then    recommendation( add_water_c )
and     text( add_water_now ).

rule    /* Using LWP to make irrigation decision for cotton */
if      method_lwp( FullIrrigationLWP )
and     crop_type( cotton )
and     lwp_value( LWPValue )
and     LWPValue =< 1.5
and     LWPValue >= 1.2
and     critical_stage( yes )
then    recommendation( water_c )
and     text( water_critical_stage_c ).

rule    /* Using LWP to make irrigation decision for cotton */
if      method_lwp( FullIrrigationLWP )
and     crop_type( cotton )
and     lwp_value( LWPValue )
and     LWPValue =< 1.5
and     LWPValue >= 1.2
and     critical_stage( no )
then    recommendation( waiting_crop_c )
and     text( waiting_lwp_crop ).

rule    /* Using LWP to make irrigation decision for soybean */
if      method_lwp( FullIrrigationLWP )
and     crop_type( soybean )
and     lwp_value( LWPValue )
and     LWPValue < 1.1
then    recommendation( water_not_s )
and     text( no_water ).

rule    /* Using LWP to make irrigation decision for soybean */
if      method_lwp( FullIrrigationLWP )
and     crop_type( soybean )
and     lwp_value( LWPValue )
and     LWPValue > 1.5
then    recommendation( add_water_s )
and     text( add_water_now ).

rule    /* Using LWP to make irrigation decision for soybean */
if      method_lwp( FullIrrigationLWP )
and     crop_type( soybean )        % for soybean
and     lwp_value( LWPValue )
and     LWPValue =< 1.5
and     LWPValue >= 1.1
and     critical_stage( yes )
```

```
then    recommendation( water_p )
and     text( water_critical_stage_s ).

rule    /* Using LWP to make irrigation decision for soybean */
if      method_lwp( FullIrrigationLWP )
and     crop_type( soybean )        % for soybean
and     lwp_value( LWPValue )
and     LWPValue =< 1.5
and     LWPValue >= 1.1
and     critical_stage( no )
then    recommendation( waiting_crop_s )
and     text( waiting_lwp_crop ).

rule    /* Using LWP to make irrigation decision for maize */
if      method_lwp( FullIrrigationLWP )
and     crop_type( maize )
and     lwp_value( LWPValue )
and     LWPValue < 1.2
then    recommendation( water_not_m )
and     text( no_water ).

rule    /* Using LWP to make irrigation decision for maize */
if      method_lwp( FullIrrigationLWP )
and     crop_type( maize )
and     lwp_value( LWPValue )
and     LWPValue > 1.3
then    recommendation( add_water_m )
and     text( add_water_now ).

rule    /* Using LWP to make irrigation decision for maize */
if      method_lwp( FullIrrigationLWP )
and     crop_type( maize )
and     lwp_value( LWPValue )
and     LWPValue =< 1.3
and     LWPValue >= 1.2
and     critical_stage( yes )
then    recommendation( water_m )
and     text( water_critical_stage_m ).

rule    /* Using LWP to make irrigation decision for maize */
if      method_lwp( FullIrrigationLWP )
and     crop_type( maize )
and     lwp_value( LWPValue )
and     LWPValue =< 1.3
and     LWPValue >= 1.2
and     critical_stage( no )
then    recommendation( water_m )
and     text( waiting_lwp_crop ).

rule    /* Using LWP to make irrigation decision for potato */
if      method_lwp( FullIrrigationLWP )
```

```
and     crop_type( potato )
and     lwp_value( LWPValue )
and     LWPValue < 0.8
then    recommendation( water_not_p )
and     text( no_water ).

rule    /* Using LWP to make irrigation decision for potato */
if      method_lwp( FullIrrigationLWP )
and     crop_type( potato )
and     lwp_value( LWPValue )
and     LWPValue > 1.0
then    recommendation( add_water_p )
and     text( add_water_now ).

rule    /* Using LWP to make irrigation decision for potato */
if      method_lwp( FullIrrigationLWP )
and     crop_type( potato )
and     lwp_value( LWPValue )
and     LWPValue =< 1.0
and     LWPValue >= 0.8
and     critical_stage( yes )
then    recommendation( water_p )
and     text( water_critical_stage_p ).

rule    /* Using LWP to make irrigation decision for potato */
if      method_lwp( FullIrrigationLWP )
and     crop_type( potato )
and     lwp_value( LWPValue )
and     LWPValue =< 1.0
and     LWPValue >= 0.8
and     critical_stage( no )
then    recommendation( waiting_crop_p )
and     text( waiting_lwp_crop ).


/*
________________________________________________________________

rules for: making irrigation decision using MAD
________________________________________________________________

*/

rule    /* determining cumulative soil moisture depletion */
if      fullIrrigation( FullIrrigationMAD )
and     crop_type( wheat )
or      crop_type( alfalfa )
or      crop_type( soybean )
or      crop_type( cotton )
or      crop_type( maize )
or      crop_type( potato )
and     soil_type( sand )
or      soil_type( 'loamy sand' )
```

```
or      soil_type( 'sandy loam' )
or      soil_type( 'silt loam' )
or      soil_type( 'clay loam' )
or      soil_type( clay )
and     soil_moisture_depletion( yes ) % Then calculate the cumulative depletion
and     rainfall( Rainfall )
and     actual_Et_rate( EtRate )
and     last_irrigation( TotalDays )
and     CumulativeMoistureDepletion = (EtRate * TotalDays - Rainfall * 0.8)
and     units( english )
and     mmToInches( CumulativeMoistureDepletion, CMD_output )
then    cmd( CumulativeMoistureDepletion_Eng )
and     text(cmd_eng, [ CMD_output ]).

rule    /* determining cumulative soil moisture depletion */
if      fullIrrigation( FullIrrigationMAD )
and     crop_type( wheat )
or      crop_type( alfalfa )
or      crop_type( soybean )
or      crop_type( cotton )
or      crop_type( maize )
or      crop_type( potato )
and     soil_type( sand )
or      soil_type( 'loamy sand' )
or      soil_type( 'sandy loam' )
or      soil_type( 'silt loam' )
or      soil_type( 'clay loam' )
or      soil_type( clay )
and     soil_moisture_depletion( yes ) % Then calculate the cumulative depletion
and     rainfall( Rainfall )
and     actual_Et_rate( EtRate )
and     last_irrigation( TotalDays )
and     CumulativeMoistureDepletion = (EtRate * TotalDays - Rainfall * 0.8)
and     units( metric )
then    cmd( CumulativeMoistureDepletion )
and     text(cmd, [ CumulativeMoistureDepletion ]).

rule    /* no information provided */
if      fullIrrigation( FullIrrigationMAD )
and     crop_type( wheat )
and     soil_moisture_depletion( no )
then    tryDifferentWay( try_some_other_way )
and     text( try_some_other_way ).

rule    /* no irrgation needed */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( ripening )
or      crop_growth_stage( harvest )
then    recommendation( NoIrrigation )
and     text( noIrrigation ).
```

```
rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                      % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100        -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AmountOfWater_Sand_eng )
and     text( aow_eng, [ NumberOfDay, AOW_output ]).


rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                      % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100        -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AmountOfWater_Sand )
and     text( aow, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100  -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
```

```
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AmountOfWater_LS )
and     text( aow, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )             % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     metric( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AmountOfWater_LS_eng )
and     text( aow_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )             % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AmountOfWater_SandyL )
and     text( aow, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
```

```
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )              % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AmountOfWater_SandyL_eng )
and     text( aow_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       %growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                      % soil type is clay or clay loam
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AmountOfWater_CL_eng )
and     text( aow_eng, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                   % soil type is clay or clay loam
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
```

```
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AmountOfWater_CL )
and     text( aow, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )              % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AmountOfWater_SiltL_eng )
and     text( aow_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )              % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate)
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AmountOfWater_SiltL )
and     text( aow, [ NumberOfDay, AmountOfWater ]).

rule    /* waiting--no irrigation needed now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      %growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
```

```
and     soil_type( sand )                    % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0             % cumulative moisture depletion >
                                             ADepletion
and     rain_chance( 'great than 60' )       % chance of rain >60%
then    recommendation( WaterAndLeaveRoom_Sand )
and     text( waterandleaveroom).

rule    /* waiting--no irrigation needed now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )     % growth stage-preplanting or
                                             planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )            % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0             % cumulative moisture depletion
                                             > ADepletion
and     rain_chance( 'great than 60' )       % chance of rain >60%
then    recommendation( WaterAndLeaveRoom_SandyL )
and     text( waterandleaveroom).

rule    /* waiting--no irrigation needed now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )     % growth stage-preplanting or
                                             planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )            % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0             % cumulative moisture depletion >
                                             ADepletion
and     rain_chance( 'great than 60' )       % chance of rain >60%
then    recommendation( WaterAndLeaveRoom_LSand )
and     text( waterandleaveroom).

rule    /* waiting--no irrigation needed now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )     % growth stage-preplanting or
                                             planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )
or      soil_type( 'clay loam' )             % soil type is clay or clay loam
and     FieldCapacity = 150
```

```
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                 CumulativeMoistureDepletion )
and     DepletionDifference =< 0           % cumulative moisture depletion >
                                           ADepletion
and     rain_chance( 'great than 60' )     % chance of rain >60%
then    recommendation( WaterAndLeaveRoom_CL )
and     text( waterandleaveroom).

rule    /* waiting--no irrigation needed now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )   % growth stage-preplanting or
                                           planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )           % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                 CumulativeMoistureDepletion )
and     DepletionDifference =< 0           % cumulative moisture depletion >
                                           ADepletion
and     rain_chance( 'great than 60' )     % chance of rain >60%
then    recommendation( WaterAndLeaveRoom_SiltL )
and     text( waterandleaveroom).

rule    /* needing  irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )   % growth stage-preplanting or
                                           planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                  % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                 CumulativeMoistureDepletion )
and     DepletionDifference =< 0           % cumulative moisture depletion >
                                           ADepletion
and     rain_chance( 'less than 60' )      % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( SupplyWater_Sand )
and     text( aow_6, [ AmountOfWater ]).

rule    /* needing irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )   % growth stage-preplanting or
                                           planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                  % soil type is sand
and     FieldCapacity = 73
```

```
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0          % cumulative moisture depletion >
                                          ADepletion
and     rain_chance( 'less than 60' )     % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( SupplyWater_Sand_eng )
and     text( aow_6_eng, [ AOW_output]).

rule    /* needing  irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )  % growth stage-preplanting or
                                          planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )         % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0          % cumulative moisture depletion >
                                          ADepletion
and     rain_chance( 'less than 60' )     % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( SupplyWater_LSand )
and     text( aow_6, [ AmountOfWater ]).

rule    /* needing  irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )  % growth stage-preplanting or planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )         % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0          % cumulative moisture depletion >
                                          ADepletion
and     rain_chance( 'less than 60' )     % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( SupplyWater_LSand_eng )
and     text( aow_6_eng, [ AOW_output ]).

rule    /* needing irrigation */
```

```
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )             % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0              % cumulative moisture depletion >
                                              ADepletion
and     rain_chance( 'less than 60' )         % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( SupplyWater_SandyL )
and     text( aow_6, [ AmountOfWater ]).

rule    /* need irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )             % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0              % cumulative moisture depletion >
                                              ADepletion
and     rain_chance( 'less than 60' )         % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( SupplyWater_LSand_eng )
and     text( aow_6_eng, [ AOW_output ]).

rule    /* needing  irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )      % growth stage-preplanting or
                                              planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                     % soil type is clay or clay loam
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0              % cumulative moisture depletion >
                                              ADepletion
```

```
and     rain_chance( 'less than 60' )          % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( SupplyWater_LSand )
and     text( aow_6, [ AmountOfWater ]).

rule    /* needing irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference = ( AllowableDepletion * FieldCapacity/100
                - CumulativeMoistureDepletion )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     rain_chance( 'less than 60' )          % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( SupplyWater_LSand )
and     text( aow_6, [ AmountOfWater ]).

rule    /* needing irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     rain_chance( 'less than 60' )          % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( SupplyWater_LSand )
and     text( aow_6, [ AmountOfWater ]).

rule    /* needing irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
```

```
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     rain_chance( 'less than 60' )          % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( SupplyWater_LSand_eng )
and     text( aow_6_eng, [ AOW_output ]).

rule    /* need irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )               % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     rain_chance( 'less than 60' )          % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( SupplyWater_SiltL )
and     text( aow_6, [ AmountOfWater ]).

rule /* needing irrigation */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( preplanting )       % growth stage-preplanting or
                                               planting
or      crop_growth_stage( planting )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )               % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     rain_chance( 'less than 60' )          % chance of rain < 60%
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( CumulativeMoistureDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( SupplyWater_SiltL_eng )
```

```
and     text( aow_6_eng, [ AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                       % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOW_Sand_eng )
and     text( aow_2_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )               % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AOW_LSand )
and     text( aow_2, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
```

```
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOW_LSand_eng )
and     text( aow_2_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )              % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AOW_SandyL )
and     text( aow_2, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )              % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
```

```
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOW_SandyL_eng )
and     text( aow_2_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                       % soil type is clay
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AOW_CL )
and     text( aow_2, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                       % soil type is clay
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOW_CL_eng )
```

```
and     text( aow_2_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )                % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                                 CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( metric )
then    recommendation( AOW_SiltL )
and     text( aow_2, [ NumberOfDay, AmountOfWater ]).

rule    /* determining when and how much to irrigate */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )                % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                                 CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     rain_chance( 'less than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOW_SiltL_eng )
and     text( aow_2_eng, [ NumberOfDay, AOW_output ]).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
```

```
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                      % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_Sand )
and     text( aow_3 ).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_LS )
and     text( aow_3 ).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )              % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
```

```
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_SandyL )
and     text( aow_3 ).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                       % soil type is clay or clay loam
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_CL )
and     text( aow_3 ).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )                % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_SiltL )
and     text( aow_3 ).

rule    /* needing irrgation soon */
if      cmd( CumulativeMoistureDepletion )
```

```
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                       % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     NumberOfDay =< 2
and     rain_chance( 'less than 60' )           % < 60% chance of rain
and     irrigation_efficiency(IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( justIrrigation_Sand )
and     text( aow_4, [ AmountOfWater ]).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )               % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_LSand )
and     text( aow_3 ).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )               % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
```

```
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_SandyL )
and     text( aow_3 ).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                       % soil type is clay or clay loam
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_CL )
and     text( aow_3 ).

rule    /* determining irrigation now */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )                % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference > 0
and     DepletionDifference =< 2
and     rain_chance( 'great than 60' )
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater = ( AllowableDepletion * 100 /IrriEfficiency )
then    recommendation( AOW_3_SiltL )
```

```
and     text( aow_3 ).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                       % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0                % cumulative moisture depletion >
                                                ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =         ( AllowableDepletion - DepletionDifference ) * 100 /
                                IrriEfficiency
and     units( metric )
then    recommendation( AOWater_Sand )          % above DepletionDifference =<0
and     text( aow_5, [ AmountOfWater ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( sand )                       % soil type is sand
and     FieldCapacity = 73
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0                % cumulative moisture depletion >
                                                ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =         ( AllowableDepletion - DepletionDifference ) * 100 /
                                IrriEfficiency
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOWater_Sand_eng )              % DepletionDifference =< 0
and     text( aow_5_eng, [ AOW_output ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
```

```
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =        ( AllowableDepletion - DepletionDifference ) * 100 /
                               IrriEfficiency
and     units( metric )
then    recommendation( AOWater_LSand )       % DepletionDifference =< 0
and     text( aow_5, [ AmountOfWater ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'loamy sand' )              % soil type is loamy sand
and     FieldCapacity = 100
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =        ( AllowableDepletion - DepletionDifference ) * 100 /
                               IrriEfficiency
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOWater_LSand_eng )        % DepletionDifference =< 0
and     text( aow_5_eng, [ AOW_output ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )              % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
```

```
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =         ( AllowableDepletion - DepletionDifference ) * 100 /
                                IrriEfficiency
and     units( metric )
then    recommendation( AOWater_SandyL )  % DepletionDifference =< 0
and     text( aow_5, [ AmountOfWater ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'sandy loam' )              % soil type is sandy loam
and     FieldCapacity = 115
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =         ( AllowableDepletion - DepletionDifference ) * 100 /
                                IrriEfficiency
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOWater_SandyL_eng )        %DepletionDifference=<0
and     text( aow_5_eng, [ AOW_eng ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )         % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                      % soil type is clay or clay loam
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0               % cumulative moisture depletion >
                                               ADepletion
```

```
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =       ( AllowabeDepletion - DepletionDifference ) * 100 / IrriEfficiency

and     units( metric )
then    recommendation( AOWater_CL )       % DepletionDifference =< 0
and     text( aow_5, [ AmountOfWater ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )       % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( clay )                    % soil type is clay or clay loam
or      soil_type( 'clay loam' )
and     FieldCapacity = 150
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0             % cumulative moisture depletion >
                                             ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =       ( AllowabeDepletion - DepletionDifference ) * 100 / IrriEfficiency

and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOWater_CL_eng )   % DepletionDifference =< 0
and     text( aow_5_eng, [ AOW_eng ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )       % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )             % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =  ( AllowableDepletion * FieldCapacity/100 -
                               CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0             % cumulative moisture depletion >
                                             ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =       ( AllowableDepletion - DepletionDifference ) * 100 /
                              IrriEfficiency
and     units( metric )
then    recommendation( AOWater_SiltL )    % DepletionDifference =< 0
```

```
and     text( aow_5, [ AmountOfWater ]).

rule    /* irrigation strategy for the crucial growth stage */
if      cmd( CumulativeMoistureDepletion )
and     crop_growth_stage( tillering )          % growth stage-tillering ...
or      crop_growth_stage( booting )
or      crop_growth_stage( heading )
or      crop_growth_stage( flowering )
and     allowable_depletion( AllowableDepletion )
and     soil_type( 'silt loam' )                % soil type is silt loam
and     FieldCapacity = 185
and     DepletionDifference =   ( AllowableDepletion * FieldCapacity/100 -
                                CumulativeMoistureDepletion )
and     actual_Et_rate( EtRate )
and     NumberOfDay = ( DepletionDifference / EtRate )
and     DepletionDifference =< 0                % cumulative moisture depletion >
                                                ADepletion
and     irrigation_efficiency( IrriEfficiency )
and     AmountOfWater =         ( AllowableDepletion - DepletionDifference ) * 100 /
                                IrriEfficiency
and     units( english )
and     mmToInches( AmountOfWater, AOW_output )
then    recommendation( AOWater_SiltL_eng ) %  DepletionDifference =< 0
and     text( aow_5_eng, [ AOW_eng ]).
```

```
/*
______________________________________________________________

rules for: fertilization management for wheat
______________________________________________________________

*/
```

```
rule    /* determining total N requirement--for low limit of nitrogen */
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
and     fertilizer_requirement( nitrogen )
and     nitrogen_data( yes )
and     LowLimit = YieldGoal * 2.4
and     HighLimit = YieldGoal * 2.7
then    nitrogen_requ( LowLimit )
and     text( n_requirement,[ LowLimit, HighLimit ]).

rule    /* determining total N requirement--for high limit of nitrogen */
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
```

```
and     fertilizer_requirement( nitrogen )
and     nitrogen_data( yes )
and     LowLimit = YieldGoal * 2.4
and     HighLimit = YieldGoal * 2.7
then    nitrogen_requ( HighLimit )
and     text( n_requirement,[ LowLimit,HighLimit ]).

rule    /* determining total N requirement--no nitrogen data available*/
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
and     fertilizer_requirement( nitrogen )
and     nitrogen_data( no )
and     LowLimit = YieldGoal * 2.4
and     HighLimit = YieldGoal * 2.7
then    other_method_n( other_method_n )
and     text( other_method_n,[ LowLimit, HighLimit ]).

rule    /* determining total P requirement--for low limit of phosphorus */
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
and     fertilizer_requirement( phosphorus )
and     phosphorus_data( yes )
and     LowLimit = YieldGoal * 0.3
and     HighLimit = YieldGoal * 0.5
then    phosphorus_requ( LowLimit )
and     text(p_requirement,[ LowLimit, HighLimit ]).

rule    /* determining total P requirement--for high limit of phosphorus */
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
and     fertilizer_requirement( phosphorus )
and     phosphorus_data( yes )
and     LowLimit = YieldGoal * 0.3
and     HighLimit = YieldGoal * 0.5
then    phosphorus_requ( HighLimit )
and     text(p_requirement,[ LowLimit,HighLimit ]).

rule    /* determining total P requirement--no phosphorus data available*/
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
```

```
and     yield_goal( YieldGoal )
and     fertilizer_requirement( phosphorus )
and     phosphorus_data( no )
and     LowLimit = YieldGoal * 0.3
and     HighLimit = YieldGoal * 0.5
then    other_method_p( other_method_p )
and     text( other_method_p,[ LowLimit, HighLimit] ).

rule    /* determining total K requirement--for low limit of potassium */
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
and     fertilizer_requirement( potassium )
and     potassium_data( yes )
and     LowLimit = YieldGoal * 1.5
and     HighLimit = YieldGoal * 2.0
then    potassium_requ( LowLimit )
and     text( k_requirement,[ LowLimit,HighLimit ]).

rule    /* determining total K requirement--for high limit of potassium */
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
and     fertilizer_requirement( potassium )
and     potassium_data( yes )
and     LowLimit = YieldGoal * 1.5
and     HighLimit = YieldGoal * 2.0
then    potassium_requ( HighLimit )
and     text( k_requirement,[ LowLimit,HighLimit ]).

rule    /* determining total K requirement--no potassium data available*/
if      is( 'Fertilization Management' )
and     crop_type( wheat )
and     wheat_type( 'Winter Wheat' )
or      wheat_type( 'Spring Wheat' )
and     yield_goal( YieldGoal )
and     fertilizer_requirement( potassium )
and     potassium_data( no )
and     LowLimit = YieldGoal * 1.5
and     HighLimit = YieldGoal * 2.0
then    other_method_k( other_method_k)
and     text( other_method_k,[ LowLimit, HighLimit ]).

rule    /* making the decision for N fertilizer --deficient nitrogen */
if      other_method_n( other_method_n )
and     water_deficit( no )
and     nitrogen_deficiency( yes )
```

```
then    recommendation( add_N_1 )
and     text( add_N_1 ).

rule    /* making the decision for N fertilizer --deficient nitrogen*/
if      other_method_n( other_method_n )
and     water_deficit( yes )
and     nitrogen_deficiency( yes )
then    recommendation( add_N_2 )
and     text( add_N_2 ).

rule    /* the decision for no N fertilizer */
if      other_method_n( other_method_n )
and     water_deficit( no )
and     nitrogen_deficiency( no )
then    recommendation( no_nitrogen_needed )
and     text( no_nitrogen_needed ).

rule    /* the decision for irrigation */
if      other_method_n( other_method_n )
and     water_deficit( yes )
and     nitrogen_deficiency( no )
then    recommendation( relieve_stress )
and     text( relieve_stress ).

rule    /* the decision for P fertilizer --deficient phosphorus */
if      other_method_p( other_method_p )
and     water_deficit( no )
and     phosphorus_deficiency( yes )
then    recommendation( add_P_1 )
and     text( add_P_1 ).

rule    /* the decision for P fertilizer --deficient phosphorus */
if      other_method_p( other_method_p )
and     water_deficit( yes )
and     phosphorus_deficiency( yes )
then    recommendation( add_P_2 )
and     text( add_P_2 ).

rule    /* the decision for no P fertilizer */
if      other_method_p( other_method_p )
and     water_deficit( no )
and     phosphorus_deficiency( no )
then    recommendation( no_P_needed )
and     text( no_P_needed).

rule    /* the decision for irrigation */
if      other_method_p( other_method_p )
and     water_deficit( yes )
and     phosphorus_deficiency( no )
then    recommendation( relieve_stress_P )
and     text( relieve_stress ).
```

```
rule    /* the decision for K fertilizer --deficient potassium */
if      other_method_k( other_method_k )
and     water_deficit( no )
and     potassium_deficiency( yes )
then    recommendation( add_K_1 )
and     text( add_K_1 ).

rule    /* the decision for K fertilizer --deficient potassium */
if      other_method_k( other_method_k )
and     water_deficit( yes )
and     potassium_deficiency( yes )
then    recommendation( add_K_2 )
and     text( add_K_2 ).

rule    /* the decision for no K fertilizer */
if      other_method_k( other_method_k )
and     water_deficit( no )
and     potassium_deficiency( no )
then    recommendation( no_K_needed )
and     text( no_K_needed).

rule    /* the decision for irrigation */
if      other_method_k( other_method_k )
and     water_deficit( yes )
and     potassium_deficiency( no )
then    recommendation( relieve_stress_K )
and     text( relieve_stress ).

rule    /* decision for no nitrogen for preplanting */
if      nitrogen_requ( LowLimit )
or      nitrogen_requ( HighLimit)
and     crop_growth_stage( preplanting )
and     geographical_area( 'humid area' )
then    recommendation( noprepalntnitrogen )
and     text( nopreplantnitrogen ).

rule    /* decision for no nitrogen before preplanting */
if      nitrogen_requ( HighLimit )
and     crop_growth_stage( preplanting )
and     nitrogen_concentration( NitrogenLevel )
and     geographical_area( 'arid area' )
or      geographical_area( 'semiarid area' )
or      geographical_area( 'subhumid area' )
and     NitrogenLevel > HighLimit
then    recommendation( nopreplantnitrogen_1 )
and     text( nopreplantnitrogen_1 ).

rule    /* decision for exact nitrogen before preplanting--no water deficit */
if      nitrogen_requ( HighLimit )
and     nitrogen_requ( LowLimit )
and     crop_growth_stage( preplanting )
```

```
and     nitrogen_concentration( NitrogenLevel )
and     geographical_area( 'arid area' )
or      geographical_area( 'semiarid area' )
or      geographical_area( 'subhumid area' )
and     water_deficit( no )
and     NitrogenLevel >= LowLimit
and     NitrogenLevel =< HighLimit
then    recommendation( exactpreplantnitrogen )
and     text( exactpreplantnitrogen ).

rule    /* decision for exact nitrogen before preplanting--water deficit */
if      nitrogen_requ( HighLimit )
and     nitrogen_requ( LowLimit )
and     crop_growth_stage( preplanting )
and     nitrogen_concentration( NitrogenLevel )
and     geographical_area( 'arid area' )
or      geographical_area( 'semiarid area' )
or      geographical_area( 'subhumid area' )
and     water_deficit( yes )
and     NitrogenLevel >= LowLimit
and     NitrogenLevel =< HighLimit
then    recommendation( exactpreplantnitrogen_w )
and     text( exactpreplantnitrogen_w ).

rule    /* decision for nitrogen needed before planting--no water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( preplanting )
and     nitrogen_concentration( NitrogenLevel )
and     geographical_area( 'arid area' )
or      geographical_area( 'semiarid area' )
or      geographical_area( 'subhumid area' )
and     water_deficit( no )
and     NitrogenLevel < LowLimit
then    recommendation( preplantnitrogen )
and     text( preplantnitrogen ).

rule    /* decision for nitrogen needed before planting--water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( preplanting )
and     nitrogen_concentration( NitrogenLevel )
and     geographical_area( 'arid area' )
or      geographical_area( 'semiarid area' )
or      geographical_area( 'subhumid area' )
and     water_deficit( yes )
and     NitrogenLevel < LowLimit
then    recommendation( preplantnitrogen_w )
and     text( preplantnitrogen_w ).

rule    /* decision for no phosphorus before planting--high P */
if      phosphorus_requ( HighLimit )
and     crop_growth_stage( preplanting )
```

```
and     phosphorus_concentration( PhosphorusLevel )
and     PhosphorusLevel > HighLimit
then    recommendation( no_preplant_phosphorus )
and     text( no_preplant_phosphorus ).

rule    /* decision for no phosphorus before planting--exact P */
if      phosphorus_requ( HighLimit )
and     phosphorus_requ( LowLimit )
and     crop_growth_stage( preplanting )
and     phosphorus_concentration( PhosphorusLevel )
and     PhosphorusLevel >= LowLimit
and     PhosphorusLevel =< HighLimit
then    recommendation( exact_preplant_phosphorus )
and     text( exact_preplant_phosphorus ).

rule    /* decision for phosphorus needed before planting--low P */
if      phosphorus_requ( LowLimit )
and     phosphorus_requ( HighLimit )
and     crop_growth_stage( preplanting )
and     phosphorus_concentration( PhosphorusLevel )
and     PhosphorusLevel < LowLimit
and     PhosphorusNeeded = ( (HighLimit + LowLimit) / 2 - PhosphorusLevel )
then    recommendation( PhosphorusNeeded )
and     text( preplant_phosphorus,[ PhosphorusNeeded ]).

rule    /* decision for no potassium needed before planting--high K */
if      potassium_requ( HighLimit )
and     crop_growth_stage( preplanting )
and     potassium_concentration( PotassiumLevel )
and     PotassiumLevel > HighLimit
then    recommendation( no_preplant_potassium )
and     text( no_preplant_potassium ).

rule    /* decision for no potassium needed before planting--exact K */
if      potassium_requ( HighLimit )
and     potassium_requ( LowLimit )
and     crop_growth_stage( preplanting )
and     potassium_concentration( PotassiumLevel )
and     PotassiumLevel >= LowLimit
and     PotassiumLevel =< HighLimit
then    recommendation( exact_preplant_potassium )
and     text( exact_preplant_potassium ).

rule    /* decision for potassium needed before planting--low K */
if      potassium_requ( LowLimit )
and     potassium_requ( HighLimit )
and     crop_growth_stage( preplanting )
and     potassium_concentration( PotassiumLevel )
and     PotassiumLevel < LowLimit
and     PotassiumNeeded = (( HighLimit + LowLimit ) / 2 - PotassiumLevel )
then    recommendation( PotassiumNeeded )
```

```
and     text( preplant_potassium,[ PotassiumNeeded ]).

rule    /* decision for no phosphorus at planting--high P        */
if      phosphorus_requ( HighLimit )
and     crop_growth_stage( planting )
and     phosphorus_concentration( PhosphorusLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded beside seed' )
or      placement_option( 'banded under seed' )
and     PhosphorusLevel > HighLimit
then    recommendation( no_planting_phosphorus )
and     text( no_planting_phosphorus ).

rule    /* decision for no phosphorus at planting--exact P */
if      phosphorus_requ( HighLimit )
and     phosphorus_requ( LowLimit )
and     crop_growth_stage( planting )
and     phosphorus_concentration( PhosphorusLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded beside seed' )
or      placement_option( 'banded under seed' )
and     PhosphorusLevel >= LowLimit
and     PhosphorusLevel =< HighLimit
then    recommendation( exact_planting_phosphorus )
and     text( exact_planting_phosphorus ).

rule    /* decision for phosphorus needed at planting--low P */
if      phosphorus_requ( LowLimit )
and     phosphorus_requ( HighLimit )
and     crop_growth_stage( planting )
and     phosphorus_concentration( PhosphorusLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded under seed' )
and     PhosphorusLevel < LowLimit
and     PhosphorusNeeded = (( LowLimit + HighLimit ) / 2 - PhosphorusLevel )
then    recommendation( planting_phosphorus )
and     text( planting_phosphorus,[ PhosphorusNeeded ]).

rule    /* decision for no nitrogen at planting--high N*/
if      nitrogen_requ( HighLimit )
and     crop_growth_stage( planting )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded beside seed' )
or      placement_option( 'banded under seed' )
and     NitrogenLevel >  HighLimit
then    recommendation( no_planting_nitrogen )
and     text( no_planting_nitrogen ).

rule    /* decision for no nitrogen at planting--exact N and no water deficit */
if      nitrogen_requ( HighLimit )
```

```
and     nitrogen_requ( LowLimit )
and     crop_growth_stage( planting )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded beside seed' )
or      placement_option( 'banded under seed' )
and     water_deficit( no )
and     NitrogenLevel >= LowLimit
and     NitrogenLevel =< HighLimit
then    recommendation( exact_planting_nitrogen )
and     text( exact_planting_nitrogen ).

rule    /* decision for no nitrogen at planting--exact N and water deficit */
if      nitrogen_requ( HighLimit )
and     nitrogen_requ( LowLimit )
and     crop_growth_stage( planting )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded beside seed' )
or      placement_option( 'banded under seed' )
and     water_deficit( yes )
and     NitrogenLevel >= LowLimit
and     NitrogenLevel =< HighLimit
then    recommendation( exact_planting_nitrogen_w )
and     text( exact_planting_nitrogen_w ).

rule    /* decision for nitrogen needed at planting--low N and no water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( planting )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( 'banded with seed' )     % application: banded with
                                                     seed.
and     water_deficit( no )
and     NitrogenLevel < LowLimit
and     geographical_area( 'semiarid area' )
then    recommendation( planting_nitrogen )
and     text( planting_nitrogen ).

rule    /* decision for nitrogen needed at planting--low N and water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( planting )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( 'banded with seed' )
and     water_deficit( yes )
and     NitrogenLevel < LowLimit
and     geographical_area( 'semiarid area' )
then    recommendation( planting_nitrogen_w )
and     text( planting_nitrogen_w ).

rule    /* decision for nitrogen needed at planting--low N and no water deficit */
if      nitrogen_requ( LowLimit )
```

```
and     crop_growth_stage( planting )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( 'banded under seed' )    % application :banded under
                                                      seed
and     water_deficit( no )
and     NitrogenLevel < LowLimit
then    recommendation( planting_nitrogen_u )
and     text( planting_nitrogen_u ).

rule    /* decision for nitrogen needed at planting--low N and water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( planting )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( 'banded under seed' )    % application: banded under
                                                      seed
and     water_deficit( yes )
and     NitrogenLevel < LowLimit
then    recommendation( planting_nitrogen_u_w )
and     text( planting_nitrogen_u_w ).

rule    /* decision for no potassium needed at planting--high K */
if      potassium_requ( HighLimit )
and     crop_growth_stage( planting )
and     potassium_concentration( PotassiumLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded beside seed' )
or      placement_option( 'banded under seed' )
and     PotassiumLevel > HighLimit
then    recommendation( no_planting_potassium )
and     text( no_planting_potassium ).

rule    /* decision for no potassium needed at planting--exact K */
if      potassium_requ( HighLimit )
and     potassium_requ( LowLimit )
and     crop_growth_stage( planting )
and     potassium_concentration( PotassiumLevel )
and     placement_option( 'banded with seed' )
or      placement_option( 'banded beside seed' )
or      placement_option( 'banded under seed' )
and     PotassiumLevel >= LowLimit
and     PotassiumLevel =< HighLimit
then    recommendation( exact_planting_potassium )
and     text( exact_planting_potassium ).

rule    /* decision for potassium needed at planting--low K--with seed */
if      potassium_requ( LowLimit )
and     crop_growth_stage( planting )
and     potassium_concentration( PotassiumLevel )
and     placement_option( 'banded with seed' )
and     PotassiumLevel < LowLimit
then    recommendation( planting_potassium )
```

```
and     text( planting_potassium ).

rule    /* decision for potassium needed at planting--low K--under seed */
if      potassium_requ( LowLimit )
and     potassium_requ( HighLimit )
and     crop_growth_stage( planting )
and     potassium_concentration( PotassiumLevel )
and     placement_option( 'banded under seed' )
and     PotassiumLevel < LowLimit
and     PotassiumNeeded = (( HighLimit + LowLimit) / 2 - PotassiumLevel )
then    recommendation( planting_potassium_u )
and     text( planting_potassium_u,[ PotassiumNeeded] ).

rule    /* decision for nitrogen needed at tillering--low N and no water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( tillering )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( topdressing )
and     water_deficit( no )
and     NitrogenLevel < LowLimit
then    recommendation( tillering_nitrogen )
and     text( tillering_nitrogen ).

rule    /* decision for nitrogen needed at tillering--low N and water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( tillering )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( topdressing )
and     water_deficit( yes )
and     NitrogenLevel < LowLimit
then    recommendation( tillering_nitrogen_w )
and     text( tillering_nitrogen_w ).

rule    /* decision for no nitrogen needed at tillering--high N */
if      nitrogen_requ( HighLimit )
and     crop_growth_stage( tillering )
and     nitrogen_concentration( NitrogenLevel )
and     placement_option( topdressing )
and     NitrogenLevel >= HighLimit
then    recommendation( no_tillering_nitrogen )
and     text( no_tillering_nitrogen ).

rule    /* decision for high protein requirement and no water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( flowering )
and     nitrogen_concentration( NitrogenLevel )
and     high_protein( yes )
and     placement_option( topdressing )
and     water_deficit( no )
and     NitrogenLevel < LowLimit
then    recommendation( flowering_nitrogen )
```

```
and     text( flowering_nitrogen ).

rule    /* decision for high protein requirement and water deficit */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( flowering )
and     nitrogen_concentration( NitrogenLevel )
and     high_protein( yes )
and     placement_option( topdressing )
and     water_deficit( yes )
and     NitrogenLevel < LowLimit
then    recommendation( flowering_nitrogen_w )
and     text( flowering_nitrogen_w ).

rule    /* decision for no high protein requirement */
if      nitrogen_requ( LowLimit )
and     crop_growth_stage( flowering )
and     nitrogen_concentration( NitrogenLevel )
and     high_protein( no )
and     NitrogenLevel < LowLimit
or      NitrogenLevel >= LowLimit
then    recommendation( no_flowering_nitrogen )
and     text( no_flowering_nitrogen ).


rule    /* when no solution found */
if      true
then    recommendation( not_found )
and     text( not_found ).


/*
________________________________________________
rule: for converting units
________________________________________________
*/

rule    /* for converting english LWP */
if      units( english )
and     lwp_value_bar( LWPbar )
and     barToMp( LWPbar, LWPmp)
then    lwp_value( LWPmp ).

rule    /* for converting metric LWP */
if      units( metric )
and     lwp_value_mp( LWPmp )
then    lwp_value( LWPmp ).

rule    /* for converting english Bar to metric Mp */
if      Mp = 0.1 * Bar
then    barToMp( Bar, Mp).
```

```
rule    /* for converting english SWP */
if      units( english )
and     swp_value_bar( SWPbar )
and     barToKp( SWPbar, SWPkp)
then    swp_value( SWPkp ).

rule    /* for converting metric SWP */
if      units( metric )
and     swp_value_kp( SWPkp )
then    swp_value( SWPkp ).

rule    /* for converting english Bar to metric kPa */
if      Kp = 100 * Bar
then    barToKp( Bar, Kp).


rule    /* for converting english actual_Et_rate */
if      units( english )
and     actual_Et_rate_in( ETin )
and     inchesToMm( ETin, ETmm)
then    actual_Et_rate( ETmm ).

rule    /* for converting metric actual_Et_rate */
if      units( metric )
and     actual_Et_rate_mm( ETmm )
then    actual_Et_rate( ETmm ).

rule    /* for converting english inch to metric mm */
if      ETmm = 25.4 * ETin
then    inchesToMm( ETin, ETmm).

rule    /* for converting metric mm to english inch */
if      In = Mm / 25.4
then    mmToInches( Mm, In).

rule    /* for converting english actual_Et_rate */
if      units( english )
and     rainfall_in( RFin )
and     inchesToMm( RFin, RFmm)
then    rainfall( RFmm ).

rule    /* for converting metric actual_Et_rate */
if      units( metric )
and     rainfall_mm( RFmm )
then    rainfall( RFmm ).

/*
________________________________________

        Text Screens
________________________________________

*/
```

```
text( irrigation_scheduling, $
	Now we are bringing you to irrigation scheduling.
$).
text( 'Fertilization Management', $
	Now we are bringing you to fertilization management.
$).
text( 'Pest Management', $
	Now we are bringing you to pest management
$).
text( cwsi, $
	Be patient to answer some quention before making irrigation decision.
$).
text( sdi, $
	Sorry! I cann't give you any advice because I don't have enough  expertise on this
index.
$).
text( cmd_eng, $
	The cumulative soil moisture depletion is [1] inches.
$).
text( cmd, $
	The cumulative soil moisture depletion is [1] mm.
$).
text( try_some_other_way, $
	Don't worry! I can help you if you give me some information for wheat.
$).
text( aow, $
	There are [1:fixed(0)] days until the next irrigation. The total amount of water is
[2:fixed(0)] mm which needs irrigating. Please mark your calendar. Preplant irrigation is widely
practiced in the Great Plains and western United States.
$).
text( aow_eng, $
	There are [1:fixed(0)] days until the next irrigation. The total amount of water is
[2:fixed(0)] inch which needs irrigating. Please mark your calendar. Preplant irrigation is widely
practiced in the Great Plains and western United States.
$).
text(water_critical_stage, $
	You need to irrigate now because water stress can cause severely reduced yield at
critical growth stages such as tillering, booting, heading, and
flowering.
$).
text(water_critical_stage_m, $
	You need to irrigate now because water stress can cause severely reduced yield at
critical growth stage such as pollination period. Pollination period is very critical if no prior
water deficit.
$).
text(water_critical_stage_p, $
	You need to irrigate now because water stress can cause severely reduced yield at
critical growth stages such as formulation of tubers and blossom to harvest.
$).
text(water_critical_stage_a, $
	You need to irrigate now because water stress can cause severely reduced yield at
```

critical growth stages such as just after cutting for hay and at the start of flowering for seed production.
$).
text(water_critical_stage_c, $
You need to irrigate now because water stress can cause severely reduced yield at critical growth stages such as flowering and boll formulation.
$).
text(water_critical_stage_s, $
You need to irrigate now because water stress can cause severely reduced yield at critical growth stages such as flowering, fruiting stage, and period of maximum vegetative growth.
$).
text(aow_1, $
You may either irrigate now or wait for a couple of days until next irrigation. It depends on your specific situation such as time factor, irrigation facility, yield goal, and irrigation strategy.
$).
text(waterandleaveroom, $
You need to apply water now but leave room for rainfall.
$).
text(aow_5, $
You need to supply [1:fixed(0)] mm water right now because your crop is suffering from severe water stress. Otherwise, crop yield will be significantly reduced.
$).
text(aow_5_eng, $
You need to supply [1:fixed(0)] inch water right now because your crop is suffering from severe water stress. Otherwise, crop yield will be significantly reduced.
$).
text(aow_6, $
You may apply [1:fixed(0)] mm water. It depends on your specific situation such as time factor, irrigation facility, yield goal, and irrigation strategy.
$).
text(aow_6_eng, $
You may apply [1:fixed(0)] inch water. It depends on your specific situation such as time factor, irrigation facility, yield goal, and irrigation strategy.
$).
text(aow_4, $
You need apply [1:fixed(0)] mm water within next two days. Please mark your calendar don't forget to irrigate. The most crititcal stages are during tillering, booting, heading, and flowering. Water shortage during these stagescan result in severely reduced yield. So you must concern about water stress at all these stages.
$).
text(di_mad, $
Now you are using MAD method to make deficit irrigation decision.
$).

text(fi_mad, $
Now you are using MAD method to make full irrigation decision.
$).
text(fi_swp, $
Now you are using soil water potential method to make full irrigation decision.

```
$).
text( fi_lwp, $
        Now you are using leaf water potential method to make full irrigation decision.
$).
text( fi_wsi, $
        Now you are using water stress indecies method to make full irrigation decision.
$).
text( di_wsi, $
        Now you are using water stress indecies method to make deficit irrigation decision.
$).
text( noIrrigation, $
        It's unnecessary to irrigate at the late riping or harvest stage.
$).
text( aow_2, $
        There are [1:fixed(0)] days until the next irrigation. The total amount of water is
[2:fixed(0)] mm which needs irrigating. Please mark your calendar.The most crititcal stages are
during tillering, booting, heading and flowering. Water shortage during these stages can result
in severely reduced yield. So you must concern about water stress at all these stages.
$).
text( aow_2_eng, $
        There are [1:fixed(0)] days until the next irrigation. The total amount of water is
[2:fixed(0)] inch which needs irrigating. Please mark your calendar.The most crititcal stages
are during tillering, booting, heading and flowering. Water shortage during these stages can
result in severely reduced yield. So you must concern about water stress at all these stages.
$).
text( aow_3, $
        You need to irrigate now but leave room for rainfall. The most crititcal stages are
during tillering,booting, heading and flowering. Water shortage during these stages can result
in severely reduced yield. So you must concern about water stress at all these stages.
$).
text( no_water, $
        You do not need to irrigate right now!
$).
text( waiting_swp_crop, $
        You may either irrigate now or wait for a couple of days until next irrigation. It depands
on your secific situations.
$).
text( need_water, $
        You need to irrigate now!
$).
text( waiting_lwp_w, $
        You may either undertake preplant irrigation or wait for a couple of days until preplant
irrigation. It depends on your specific situation such as time factor, irrigation facility, yield goal,
and irrigation strategy.
$).
text( waiting_lwp_crop, $
        You may either irrigate now or wait for a couple of days until next irrigation. it depends
on your specific situation such as time factor, irrigation facility, yield goal, and irrigation
strategy.
$).
text( add_water_now, $
```

Irrigate right now. Otherwise, Yield will be severely reduced. If you want to know how much water you need to apply, you should go to the Management Allowed Depeltion, a irrigation timing criterion. Using this criterion, I can tell you how much water to apply.
$).
text(nopreplantnitrogen, $
Preplant application of nitrogen for winter wheat is not a common practice in humid wheat porduction areas.
$).
text(nopreplantnitrogen_1, $
The concentration of nitrogen in the soil is so high. You do not apply nitrogen any more.
$).
text(exactpreplantnitrogen, $
The nitrogen concentration in the soil just satisfies the total requirement for the health wheat production. Just keep idle and do not apply nitrogen and water.
$).
text(exactpreplantnitrogen_w, $
The nitrogen concentration in the soil just satisfy the total requirement for the health wheat production. One thing that you need to do is to make irrigation decision.
$).
text(preplantnitrogen, $
You may apply nitrogen before planting wheat. However, applying nitrogen and other nutrients at the time of planting rather than before planting may improve crop health and fertilizer-use efficiency. Please note that applying all the nitrogen before planting can result in more lodging and also excessive losses of the nitrient because of leaching or denitrification.
$).
text(preplantnitrogen_w, $
At first, you need to irrigate to relieve water stress(please refer to irrigation scheduling). Then you may apply nitrogen before planting wheat.
$).
text(no_preplant_phosphorus, $
The concentration of phosphorus in the soil is so high. You do not apply phosphorus any more.
$).
text(exact_preplant_phosphorus, $
The concentration of phosphorus in the soil just satisfies the total requirement for the health wheat production. Do not apply the phosphorus.
$).
text(preplant_phosphorus, $
You may apply about [1:fixed(0)] pounds of phosphorus per acre in broadcast before planting,but phosphorus applied before planting can be less accessible or available to wheat than applied at planting.
$).
text(no_preplant_potassium, $
The concentration of potassium in the soil is so high. You do not apply potassium any more.
$).
text(exact_preplant_potassium, $
The concentration of potassium in the soil just satisfies the total requirement for the health wheat production. Do not apply the potassium.
$).

text(preplant_potassium, $
You may apply about [1:fixed(0)] pounds of potassium per acre in broadcast before planting, but potassium applied before planting can be less accessible or available to wheat than applied at planting. Potassium deficiencies are usually limited to sandy,highly leached soils where annual rainfall is well in excess of the annual evaporative demand.
$).
text(n_requirement, $
The total nitrogen requirement is about [1:fixed(0)] - [2:fixed(0)] pounds per acre for your yield goal. (A healty wheat crop in North America generally needs about 2.4-2.7 pounds of nitrogen per acre for every bushel of grain produced per acre.)
$).
text(p_requirement, $
The total phosphorus requirement is about [1:fixed(0)] - [2:fixed(0)] pounds per acre for your yield goal. (A healty wheat crop needs about 0.3-0.5 pound of pphosphorus for each bushel of grain produced per acre.)
$).
text(k_requirement, $
The total potassium requirement is about [1:fixed(0)] - [2:fixed(0)] pounds per acre for your yield goal.(A health wheat crop needs about 1.5-2.0 pounds of potassium for each bushel of grain produced per acre. Most soils of the Great Plains and the Pacific Northwest have adequate potassium for normal healty growth of wheat.)
$).
text(other_method_n, $
Don't worry about no soil texture data available. As long as you provide some basic information a little later, I will give you some help in the fertilizer decision making. The total nitrogen requirement is about [1:fixed(0)] - [2:fixed(0)] pounds per acre for your yield goal.
$).
text(other_method_p, $
Don't worry about no soil texture data available. As long as you provide some basic information a little later, I will give you some help in the fertilizer decision making. The total phosphorus requirement is about [1:fixed(0)] - [2:fixed(0)] pounds per acre for your yield goal.
$).
text(other_method_k, $
Don't worry about no soil texture data available. As long as you provide some basic information a little later, I will give you some help in the fertilizer decision making. The total potassium requirement is about [1:fixed(0)] - [2:fixed(0)] pounds per acre for your yield goal.
$).
text(add_N_1, $
Your wheat plants need nitrogen for normal growth and development and you should apply a certain amount of nitrogen. For more information, please contact the extention service or agent.
$).
text(add_N_2, $
At first, you need to irrigate to relieve the water stress(please refer to irrigation scheduling). If the symptoms of nitrogen deficiency is still existing, you may apply a certain amount of nitrogen to the crop.
$).
text(no_nitrogen_needed, $
It seems the symptoms of nitrogen deficiency haven't existed so far. So, you do not need apply the nitrogen now.
$).

```
text( relieve_stress, $
        You need to irrigate to relieve the water stress. Otherwise, the crop yield will be
reduced.
$).
text( add_P_1, $
        You should apply a certain amount of phosphorus because one of symptoms of the
deficiency is existing now.
$).
text( add_P_2, $
        At first, you need to irrigate to relieve the water stress(please refer to irrigation
scheduling). Then, you may apply a certain amount of phosphorus to the crop.
$).
text( no_P_needed, $
        It seems the symptoms of the phosphorus  deficiency haven't existed so far. So, you
do not need apply the phosphorus now.
$).
text( add_K_1, $
        You should apply a certain amount of potassium because one of symptoms of the
deficiency is existing now.
$).
text( add_K_2, $
        At first, you need to irrigate to relieve the water stress(please refer to irrigation
scheduling). Then, you may apply a certain amount of potassium to the crop.
$).
text( no_K_needed, $
        It seems the symptoms of the potassium deficiency haven't existed so far. So, you do
not need apply the potassium now.
$).
text( no_planting_phosphorus, $
        The concentration of phosphorus in the soil is so high. You do not apply  phosphorus
any more.
$).
text(exact_planting_phosphorus, $
        The concentration of phosphorus in the soil just satisfies the total requirement for the
health wheat production. Do not apply the phosphorus.
$).
text( planting_phosphorus, $
        You need to apply [1:fixed(0)] pounds of phosphorus per acre.
$).
text( no_planting_nitrogen, $
        The concentration of nitrogen in the soil is so high. You do not apply nitrogen any
more.
$).
text( exact_planting_nitrogen, $
        The nitrogen concentration in the soil just satisfies the total requirement for the health
wheat production. Just keep idle and do not apply nitrogen and water.
$).
text( exact_planting_nitrogen_w, $
        The nitrogen concentration in the soil just satisfies the total requirement for the health
wheat production. One thing that you need to do is to make irrigation decision.
$).
```

```
text( planting_nitrogen, $
        Generally, no more than 15 - 30 pounds of nitrogen per acre (depending on the
formulation) can be placed safely with the seed in semiarid area. Substantially higher rates are
possible in high-precipitation areas with a wet seed zone. Applying all the nitrogen at planting
can result in more lodging and also excessive losses of the nutrient because of leachinf or
denitrification.
$).
text( planting_nitrogen_w, $
        At first, you need to irrigate to relieve water stress(please refer to irrigation
scheduling). Then you may apply nitrogen at planting. Generally, no more than 15 - 30
pounds of nitrogen per acre (depending on the formulation) can be placed safely with the
seed in semiarid area.
$).
text( no_planting_potassium, $
        You do not need to apply potassium any more. Because there is enough potassium in
the soil.
$).
text(exact_planting_potassium, $
        The concentration of potassium in the soil just satisfies the total requirement for the
health wheat production. Do not apply the potassium.
$).
text( planting_potassium, $
        Application rates of potassium fertilizer applied with the seed should be kept low,
since it can also damage seed germination and seedling establishment. Fertilizer guides grom
the Cooperative Extension Service can provide more specific recommendations for fertilizer
placement with the seed in your area. Potassium deficiencies are usually limited to sandy,
highly leached soils where annual rainfall is well in excess of the annual evaporative demand.
$).
text( planting_potassium_u, $
        You need to apply [1:fixed(0)] pounds of potassium per acre. But please note that a
minimum separation of about 2 inches(5 cm) between the seed and the fertilizer band is
needed in a silt loam soil. A wider separation may be needed in coarse-textured soil.
$).
text( planting_nitrogen_u, $
        You may apply nitrogen at the low rate. Because applying all the nitrogen at planting
can result in more lodging and also excessive losses of the nitrient because of leaching or
denitrification. Also, a minimum separation of about 2 inches(5 cm) between the seed and the
fertilizer band is needed in a silt loam soil. A wider separation may be needed in
coarse-textured soil.
$).
text( planting_nitrogen_u_w, $
        At first, you need to irrigate to relieve water stress(please refer to irrigation
scheduling). Then You may apply nitrogen at the low rate. Because applying all the nitrogen at
planting can result in more lodging and also excessive losses of the nitrient because of
leaching or denitrification. Also, a minimum separation of about 2 inches(5 cm) between the
seed and the fertilizer band is needed in a silt loam soil. A wider separation may be needed in
coarse-textured soil.
$).
text( no_tillering_nitrogen, $
        You do not need to apply nitrogen any more. Because there is enough nitrogen in the
soil.
```

```
$).
text( tillering_nitrogen, $
        Topdressing(split application) to match plant size and production requires that the
nitrogen be applied no later than the onset of stem extension. A deficiency of nitrogen(or anu
other plant nitrient) during this critical stage of plant development can limit yields significantly.
$).
text( tillering_nitrogen_w, $
        At first, you need to irrigate to relieve water stress(please refer to irrigation
scheduling).Topdressing(split application) to match plant size and production requires that the
nitrogen be applied no later than the onset of stemextension. A deficiency of nitrogen(or any
other plant nitrient) during this critical stage of plant development can limit yields significantly.
$).
text( flowering_nitrogen, $
        As a general rule, nitrogen should be applied within 7 days of 50% anthesis; later
applications are used less efficiently and have less effect on grain protein. So you can apply
the remainder of nitrogen at this stage for high grain protein.
$).
text( flowering_nitrogen_w, $
        At first, you need to irrigate to relieve water stress(please refer to irrigation
scheduling).As a general rule, nitrogen should be applied within 7 days of 50% anthesis; later
applications are used less efficiently and have less effect on grain protein. So you can apply
the remainder of nitrogen at this stage for high grain protein.
$).
text( no_flowering_nitrogen, $
        You do not need to apply nitrogen any more. Later applications may affect the protein
content but are too late to affect the major yield components, such as the number of tillers
and the size of the heads.
$).
text( not_found, $
        No recommendation can be generated for you circumstance.
$).
```

APPENDIX C

IRRIGATION SCENARIOS

Following scenarios derive from the knowledge base for irrigation management. Irrigation timing criteria and some other methods have been used to making irrigation decisions. The current research mainly focus on the conventional irrigation strategy. The deficit irrigation strategy will be considered in the future, if possible.

Scenario 1

Field Conditions

Crop type is wheat

CWSI value < 0.3 ($CWSI = [((T_c - T_a) - (T_c - T_a)_l / (T_c - T_a)_u - (T_c - T_a)_l)]$. CWSI varies from a value of zero for no water stress to a maximum value of one at severe stress.)

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: No irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 2

Field Conditions

Crop type is wheat

CWSI value ≥ 0.3

CWSI value ≤ 0.5 ($CWSI = [((T_c - T_a) - (T_c - T_a)_l / (T_c - T_a)_u - (T_c - T_a)_l)]$. CWSI varies from a value of zero for no water stress to a maximum value of one at severe stress.)

crop growth stage: tillering (or booting or heading or flowering)

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation. At the critical stages such as tillering, booting, heading and flowering, any water stress can cause reduced yield.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 3

Field Conditions

Crop type is wheat

CWSI value > 0.5 ($CWSI = [((T_c - T_a) - (T_c - T_a)_l / (T_c - T_a)_u - (T_c - T_a)_l)]$. CWSI varies from a value of zero for no water stress to a maximum value of one at severe stress.)

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation. Otherwise, yield will be severely reduced.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 4

Field Conditions

Crop type is wheat or ...

Crop growth stage is ripening (or harvest)

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: No irrigation. It's unnecessary to irrigate at the late ripening or harvest stage.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 5

Field Conditions

Crop type is wheat (or alfalfa or soybean or potato or cotton or maize)

Crop growth stage is preplanting or planting

cumulative soil moisture depletion(CSMD) < allowable depletion(AD)

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation later. There are ((AD-CSWD)/average Et rate) days until the next irrigation. The total amount of water is ((AD*field capacity)/irrigation efficiency) mm which needs irrigating. Please mark your calendar. Preplant irrigation is widely practiced in the Great Plains and western United States.

Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 6

Field Conditions

Crop type is wheat
Crop growth stage is tillering(or booting or heading or flowering)
cumulative soil moisture depletion(CSMD) < allowable depletion(AD)
a number of day = ((AD-CSWD)/Average Et Rate) $\leq$ 2
chance of rain within next 2 days > 60%

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: You need to irrigate but leave room for rainfall. within the next 2 days. The most critical stages are during tillering, booting, heading and flowering. Water shortage during these stages can result in severely reduced yield. So you must concern about water stress at all these stages.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 7

Field Conditions

Crop type is wheat
leaf water potential(LWP) value > -1.4 MPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 8

Field Conditions

Crop type is wheat
LWP value $\geq$ -1.9 MPa
LWP value $\leq$ -1.4 Mpa
Crop growth stage is tillering(or booting or heading or flowering)

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation. At the critical stages such as tillering, booting, heading, and flowering, water deficit may result in reduced yield.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 9

Field Conditions
Crop type is alfalfa
leaf water potential(LWP) value > -1.0 MPa
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: No irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 10

Field Conditions
Crop type is potato
LWP value < -1.0 MPa
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation. Otherwise, yield will be severely reduced.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 11

Field Conditions

Crop type is potato
LWP value ≥ -1.0 MPa
LWP value ≤ -0.8 MPa
crop is in the critical growth stage
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation. You need to irrigate now because water stress can cause severely reduced yield at critical growth stages such as flowering, fruiting stage, and period of maximum vegetative growth.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 12

Field Conditions

crop type is wheat
soil type is sandy loam
soil water potential(SWP) > -80 kPa
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 13

Field Conditions

crop type is wheat
soil type is sandy loam
SWP ≥ -90 kPa
SWP ≤ -80 kPa
crop is in the critical growth stage
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation. At the critical stages, water stress can cause reduced yield.
Domain Expert Recommendation:

Reasons For Recommendation?

<u>Scenario 14</u>

Field Conditions

crop type is wheat
soil type is clay loam
SWP > -140 kPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: No irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

<u>Scenario 15</u>

Field Conditions

crop type is cotton
soil type is silt loam
SWP ≤ -100 kPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 16

Field Conditions

crop type is alfalfa
soil type is sandy loam
SWP > -80 kPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: No irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 17

Field Conditions

crop type is alfalfa
soil type is clay loam
SWP ≤ -150 kPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 18

Field Conditions

crop type is maize
soil type is sandy loam
SWP > -80 kPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: No irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 19

Field Conditions

crop type is soybean
soil type is silt loam
SWP $\leq$ -150 kPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 20

Field Conditions

crop type is potato
soil type is silt loam
SWP > -50 kPa

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: No irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 21

Field Conditions

crop type is potato
soil type is clay loam
SWP ≥ -80 kPa
SWP ≤ -60 kPa
crop is in the critical growth stage

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: Irrigation. At the critical growth stages, water stress can cause reduced yield.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 22

Field Conditions

Crop type is wheat or ...
Crop growth stage is early (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is ok (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).
Soil texture is fine (fine is clay loam to clay; coarse is sandy to sandy loam).

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 23

Field Conditions

Crop type is wheat or ...

Crop growth stage is early (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is ok (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).
Soil texture is coarse (fine is clay loam to clay; coarse is sandy to sandy loam).

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 24

Field Conditions

Crop type is wheat or ...
Crop growth stage is early (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is wilting (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 25

Field Condition

Crop type is wheat or ...
Crop growth stage is early (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is dry (wet is > 65%; moist is > 50% and ≤ 65%; medium is

≤ 50% and > 35%; dry ≤ 35%).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

<u>Scenario 26</u>

Field Condition
Crop type is wheat or ...
Crop growth stage is mid (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is wet or moist (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

<u>Scenario 27</u>

Field Conditions
Crop type is wheat or ...
Crop growth stage is mid (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is ok (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).
Soil texture is fine (fine is clay loam to clay; coarse is sandy to sandy loam).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions

Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 28

Field Conditions

Crop type is wheat or ...
Crop growth stage is mid (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is wilting (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 29

Field Condition

Crop type is wheat or ...
Crop growth stage is mid (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is dry (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 30

Field Condition

Crop type is wheat or ...
Crop growth stage is late (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is wet (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 31

Field Conditions

Crop type is wheat or ...
Crop growth stage is late (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is moist (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Soil texture is fine (fine is clay loam to clay; coarse is sandy to sandy loam).

Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 32

Field Conditions

Crop type is wheat or ...
Crop growth stage is late (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).

Soil moisture level is moist (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Soil texture is coarse (fine is clay loam to clay; coarse is sandy to sandy loam).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 33

Field Conditions

Crop type is wheat or ...
Crop growth stage is late (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is wilting (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

Scenario 34

Field Conditions

Crop type is wheat or ...
Crop growth stage is late (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is ok (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).

Soil texture is coarse (fine is clay loam to clay; coarse is sandy to sandy loam).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

<u>Scenario 35</u>

Field Conditions

Crop type is wheat or ...
Crop growth stage is late (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is medium (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Crop appearance is ok (ok means that the crop looks healthy; wilting means it is showing signs of moisture stress).
Soil texture is fine (fine is clay loam to clay; coarse is sandy to sandy loam).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: no irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?

<u>Scenario 36</u>

Field Condition
Crop type is wheat or ...
Crop growth stage is late (early is planting through tillering; mid is booting through soft dough; late is medium dough through maturity).
Soil moisture level is dry (wet is > 65%; moist is > 50% and ≤ 65%; medium is ≤ 50% and > 35%; dry ≤ 35%).
Is This Scenario Realistic?

Other Questions TO Consider:

What Other Information Would You Like To Have To Make This Decision, What Assumptions Are You Making?

Expert System Recommendation: irrigation.
Domain Expert Recommendation:

Reasons For Recommendation?