Egyptian Research Program for Developing Expert Systems in Agriculture

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Abstract: This paper presents briefly the achievements and results of the five years research program (92 to 97) on expert systems in agriculture in Egypt as expert system technology was identified as a useful tool for technology transfer in the extension services. The research program has three objectives: developing tools and methodologies to facilitate building expert systems for different Crops, building expert systems for production management of five crops, and studying the effect of expert systems usage on social and economic aspects. A complete methodology that covers knowledge engineering and software engineering has been developed. A tool based on logic programming and object oriented programming paradigms (KROL) was built. Five expert systems for cucumber, tomato, orange, lime, and wheat were developed. The evaluation of the five expert systems showed their performances are comparable to human experts. The economic, environment and human resources impacts of using expert systems were studied. The economic impact was estimated to be 23% and 26% approximately for production of cucumber and wheat respectively. The conservation of environment was also observed when the recommended amounts of chemicals are compared with the traditional practices. The positive impact on enhancing the performance of extension workers was noticed in their decision-making capabilities.

Introduction

The transfer of knowledge from consultants & scientists to Agriculturists, Extension workers and farmers represents a bottleneck for the development of agriculture on the national level. The current era is witnessing a vast development in all fields of Agriculture. Therefore there is a need for an unconventional method to transfer the knowledge of experts in certain domain to the general public of farmers, especially that the number of experts in new technologies is lesser than their demand in a certain domain. The Egyptian Ministry of Agriculture (MOA) has decided to investigate the usage of expert systems technology to respond to this need. The Central Laboratory for Agricultural Expert Systems (CLAES) has been established in 1991 to conduct research in the area of expert systems in agriculture. A first 5 years research plan was prepared for the period from 1992 to1997. The objectives of this research plan were to 1) developing tools and methodologies to facilitate building expert systems for different crops. 2) building expert systems for production management of cucumber under plastic tunnel, tomato, orange, lime, and wheat. 3) studying the effect of expert systems usage on social and economic aspects. the estimated benefits from the plan execution were the improvement of knowledge engineer performance, the optimization of agriculture production and the improvement of extension workers performance.

The research program has achieved its objectives. Rafea et al. (1993) presented an earlier version of the methodology that was based on system engineering approach. This knowledge engineering methodology evolved to be based on Knowledge Analysis and Design Structuring (KADS) approach. (Rafea et al., 1994), (Abdelhamid et al., 1997). A tool based on object and logic programming paradigms (KROL) has been built (Shaalan et al.,1998). This tool has been used for building three out of the five expert systems developed.

Four expert systems, for cucumber (Rafea et al.,1995), tomato (El-Shishtawi et al., 1995), orange (Salah et al.,1993), and lime (Mahmoud, et al., 1997), have been built using the developed methodology and one expert system, for wheat (Kamel et al., 1995), has been built using the Generic Task (GT) Methodology. In effect, each expert system consists of a set of subsystems covering different areas of crop management namely: variety selection, planting, irrigation, fertilization, pest control and others.

The impact of using expert system for managing cucumber production under plastic tunnels (CUPTEX) has been studied by conducting field experiment in 6 locations. The field test results proved that CUPTEX is very useful in reducing cost, and increasing yield. The net production increase was $382 per tunnel which represents 23.3% increase in production (Rafea et al., 1995). Another experiment was conducted to measure the economic impact of using the wheat expert system in 32 fields. It was found that the net production increase was $126 per feddan (1 feddan = .42 hectare = 1.04 acres) which represents 26.4% increase in the production . The impact on enhancing the performance of the extension workers when using the expert system was also measured. A tangible enhancement was observed which ranges from 80% to 157% according to the different subsystems of the cucumber system and with an average enhancement of 102%. A tangible enhancement was also observed in users of orange system, which was estimated to be 579% on average. In the wheat system the enhancement in the performance of the extension workers using the system was estimated to be 125%.

In the following sections the research program achievements will be described in some details. Section two will present the methodology and tool developed. Section three will describe each of the five expert systems. Section 4 will discuss the impact of the deployed expert systems.

Development of Expert Systems Methodologies and Tools

The research program on expert system emphasized from its early beginning the importance of having a structured methodology for developing expert system. The effort started with a system engineering approach that has been evolved later to second-generation approach. Building tools was also a main concern as building our own tool, we can respond to user needs more effective than having a black box environment. The following subsections introduce the achieved methodology and the tool developed at CLAES.

The Development Methodology

The methodology is divided into two main parts: knowledge engineering, and software engineering. The two parts of the methodology are interacting through a spiral model. The output of the knowledge engineering process is fed into the input of the software engineering activities. The main interaction is through feeding the results of the knowledge analysis phase into the design activity. The methodology also preserves the design model through introducing a method to transfer the design into an expert system development shell. This methodology [Rafea, et al., 1994] has been based on a KADS [Wielinga et al., 1992].

Knowledge Engineering Methodology

The knowledge engineering methodology included: acquiring the knowledge, analyzing and modeling the acquired knowledge, and verifying the modeled knowledge.

The knowledge was acquired using structured interview, concept sorting, and protocol analysis techniques. The knowledge engineering team consisted of two knowledge engineers, and five domain experts in the following specialties: production, irrigation, nutrition, plant pathology, and entomology. The developed prototypes were also used as an automated tool for refining the acquired knowledge. The acquired knowledge is documented in different forms pending on the knowledge type. We found that dependency network can be used to represent the domain knowledge relations effectively. It was also found that using dependency network was very successful in communication with the domain experts. During this phase, all types of media that can be used to enhance the explanation capabilities of the systems were collected such as images, video clips and texts.

The knowledge analysis and modeling procedure included: domain analysis, inference analysis, and task analysis. Domain analysis: The documented knowledge was analyzed aiming at identifying concepts, properties of these concepts, and relations. The relations are either relations between concepts or relation between expressions. Concepts and relations found to be used by more than one subsystem were identified and grouped in a common knowledge base. Inference analysis: The documents and tapes generated from knowledge acquisition activities were analyzed with the purpose of finding the domain knowledge which the expert was using to reach a conclusion from specific components in the domain layer. So, the inference analysis was aiming at modeling the acquired knowledge. This analysis was guided by the inference layer structure described by KADS. The project has succeeded in developing a set of interpretation models for the crop management domain. These models can be used later for developing any crop management expert system. Task analysis: The task analysis was aiming at finding the sequence or the procedure, which the expert used to reach a final conclusion. This analysis phase is skipped when we used the GT approach as the GT approach provides a model for each generic task such as diagnosis and routine design (Chandrasekaran, 1988)

The knowledge was verified at the knowledge acquisition stage, analysis stage and implementation stage. Reviewing, at the elicitation stage, was conducted by letting the domain experts review the results of the knowledge elicitation sessions. Reviewing, at the analysis and modeling stage was conducted by letting the domain experts review the filled forms describing the domain layer. It was difficult for the domain experts to review the inference and task layers as described here. Therefore, the task layer was explained in natural language and approved by the expert as a valid way for solving the problem. Reviewing at the implementation stage was conducted by letting the domain experts review early any prototype. Multiple experts conflict resolution was considered as some sort of verifying the acquired knowledge. This was because when two experts gave different knowledge for the same thing, then trying to resolve this conflict yielded more reliable knowledge. If no consensus was reached the view of the expert recognized to be more specialized in the area of disagreement was considered.

Software Engineering Methodology

The software engineering team consisted of two software engineers. The approach we proposed for software development was a combination of rapid prototyping, incremental, and traditional methods. The rapid prototyping was used first to complete the requirement specifications. The incremental model started by implementing the Laboratory prototype and ended by implementing the production version. The software development included a set of activities: requirement specifications, design, implementation, and testing.

Requirement Specifications: An initial set of requirement specifications was determined as a result of early knowledge elicitation activity. This initial set was the basis for further knowledge acquisition efforts and the basis for the preliminary design of the research prototype. The requirement specifications were revised regularly after each prototype implementation.

Design: A preliminary design was done just after the set of initial requirements specifications were determined, and a preliminary model of knowledge layers was specified. This design was the basis for the research prototype that was used to produce the requirement specifications for the laboratory prototype. The design was revised after the implementation of each prototype. Major areas, to be considered in the design, were the representation of knowledge, interfaces, explanation, database, multimedia component, and control strategy.

Implementation: The first decision taken after the approval of the design was the selection of the implementation tool. This decision was based on: the knowledge representation supported, interfaces to external modules, explanation facilities, the primitives, provided, to code the control mechanism, and hardware and software needs for system delivery. Although using a shell speeds up the implementation process, the project experience identified these two major constraints on using shells. First, implementing a special explanation module and/or a special control mechanism is unfeasible in less expensive tools. Second, the delivery of a developed system needs a runtime license for expensive tools that give the user the environment to customize an application, which may cost about $1200. Therefore, we build our own tool on top of the programming language PROLOG.

Verification & Validation: The prototypes and production versions were verified through running cases acquired from the design. The validation was done through getting the acceptance of the domain experts participated in the development.

Evaluation: External domain experts have evaluated the field prototype before being fielded. The evaluation methodology was simply conducted by generating test cases, distributing these cases to three domain experts and to the expert system, and letting a senior domain expert evaluate the four sets of cases blindly. This means that he does not know the cases of the human experts those produced by the expert system. The evaluator just gives a grade for each case like: excellent, good, acceptable and not acceptable. Another type of evaluation was done through getting the comments of the end users.

Expert Systems Building Tool

A new knowledge representation language that combines logic, object-oriented and rule-based programming paradigms was designed. We called this language Knowledge Representation Object Language (KROL). This language provided a good medium for the second-generation expert systems development. Nevertheless, from a practical point of view, we have found more attractive to design the new language as an extension of the existing Prolog system. Knowledge base development tools that facilitate application development were also designed.

The main facilities that KROL provides are: the expressive power to represent complex knowledge, the multi-paradigm knowledge representation, modularizing a knowledge base, controlling inheritance of properties thorough a concept hierarchy, writing inference mechanisms at different level of granularity, the knowledge base development tools, the primitives that allow for higher level knowledge base modeling approaches to scale to large problems, and the synergy of different inference mechanisms in one system.

Building Expert Systems

The five expert systems developed have the same subsystems in general. However, for different reasons, some subsystems were not include in some of the expert systems. Table 1 summarizes the contents of each expert system. The five expert systems were evaluated after the laboratory prototypes had been developed. It was surprising that although the systems were not matured, the expert systems performances were comparable to human experts as can be seen from the last column of Table 1. The following subsections describe briefly the five expert systems

Expert Systems for Cucumber

The first expert system has been developed for cucumber seedling production under plastic tunnels. (Rafea et al.,1991). This prototype has six functions: seed cultivation, media preparation, controls environmental growth factors, diagnosis, treatment, and protection. It was implemented in EXSYS Professional. Although the design did include Frames, the implementation was completely in rules. This was because the frames support in the shell was limited. The implementation has used the Hypertext facility included in the shell. The overall control was implemented using the language provided by the tool and consequently, the rule base was divided into modules according to the system functions. This is in addition to the developed hypertext and image files for explanation

The expert system for managing cucumber in the production tunnel (CUPTEX) consists of two subsystems namely agriculture practice management, and disorder diagnosis and treatment. The management part consists of three modules: plant care, irrigation, and fertilization. The main function of the plant care module is to generate three types of agricultural operations to protect plants from weeds, insects and diseases, and to keep the plantation in an optimal condition. The main function of the irrigation module is to generate an irrigation schedule that includes water quantity and application frequency. The main function of the fertilization module is to generate a fertilization schedule that includes the amounts and application frequency of different fertilizers. The main function of the disorder diagnosis and treatment subsystem is to generate a prescription to protect a certain disorder or a set of disorders. In case that the user suspects the cause of disorder(s), he/she can provide the system with his/her suspicion, and the system confirms or rejects this suspicion. If the user has no suspicion, he/she can provide the system with the symptoms of the disorders, and the system identifies the cause(s) of the disorder(s). CUPTEX was firstly developed using the commercial shell NEXPERT/OBJECT and then ported to KROL (Rafea et al., 1995).

Expert Systems for Citrus

The expert system for managing orange(CITEX) consists of three subsystems namely site assessment, agriculture practice management, and disorder diagnosis and treatment. The main function of the site assessment subsystems is to generate one of these decisions : the site is perfect for cultivation, a set of treatment operations has to be applied to enhance the soil and water characteristics, or the site is not suitable for cultivation. (Salah, et al. ,1992). The functions of the agriculture practice management (Salah,et al,1993), and disorder diagnosis and treatment subsystems are the same as the corresponding subsystem of CUPTEX. CITEX was developed using NEXPERT/OBJECT commercial shell and then ported to KROL as CUPTEX.

Expert System for Wheat

In this system, the integration of a simulation model with the expert system has been done using the well-known CERES simulation model. The expert system (NEPER) included two subsystems: the strategic subsystem, and the tactical subsystem (Kamel et al., 1995). The strategic subsystem consists of 6 modules namely: variety selection, pre-cultivation pest control, tillage, planting, irrigation and fertilization, and harvest. The main function of the variety selection module is to identify the appropriate variety for a specific field based on various parameters such as the soil type, the weather, resistance to certain disease and others. The main function of the pre-cultivation pest control module is to generate recommendations of the preventive operations that should be done before cultivation based on the previous crop, and other field specific historical data. The function of the tillage module is to select the appropriate machinery for tiling, and decide on the tiling method based on soil type, previous crop and other parameters. The function of the planting module is to decide on the planting date, distance between plants and method of planting. Irrigation and fertilization are similar to what has been describer earlier. The only difference is that they are using the CERES model to calculate the water quantity and nitrogen quantity. The function of the harvest module is to generate recommendation concerning the harvest date, harvest machinery, and storing the grains. The tactical subsystem consists of two modules namely: weed identification and control, and diagnosis and treatment. The weed identification and control module is a picture based system such that the user can identify the weed in the field easily and then the system provides advice to control this weed (Schulthess et al., 1995). The diagnosis and treatment module is similar to the corresponding module in the other systems. NEPER was implemented using a tool developed at Michigan State University on top of the object-oriented language Small Talk.

Expert System for Lime

The expert system for managing lime crop (LIMEX) consists of three subsystems namely: site assessment, agriculture practice management, and pest control. The site assessment and agriculture practice management are similar to the corresponding CITEX subsystems. However, in the LIMEX irrigation and fertilization modules which are part of the agriculture practice subsystem, a feature was added to control the flowering of the lime tree. This feature is very important to help growers in determining the harvest date and consequently will help them in marketing. The main function of the pest control subsystem is to generate advice to control a certain pest. This subsystem does not contain a diagnosis module. It only verifies the existence of a certain pest before advising about LIMEX was implemented using CLIPS shell. expert system. LIMEX was integrated with textual data base that contains extension documents, images, sound, and video clips (Mahmoud et al, 1997).

Expert System for Tomato

In order to determine the scope of the tomato expert system (TOMATEX), a survey has been conducted. The results of the survey showed that there is a lack of knowledge in different aspects of crop management, especially in pest management. Therefore, it was decided to concentrate on the identification and treatment of insects and diseases. The Dependency Network was used to document the acquired domain knowledge in a pictorial form (El-Shishtawi et al., 1995). The system was implemented first using the Level 5 shell then it was ported to KROL.

Impact of the Deployed Expert Systems

We will describe, in this section, the economical, environmental, and human resources development impacts of the expert systems. This will be done through showing the results of experiments conducted using the expert systems for cucumber, orange, and wheat.

Economical Impact

During the year 95/96, an experiment was conducted in six sites: Bousily-, Noubaria, Toukh, Haram, Douki and Mariot for two purposes: first, to validate the system in the field, and to measure the impact of using the system. The experiment was conducted by selecting two tunnels: one was to be cultivated using CUPTEX without any interference from the agriculture engineer, and the other one was to be cultivated as usual, this is a control tunnel. The field test results proved that CUPTEX is very useful in reducing cost, and increasing yield. The average total cost has decreased from $478.95 to $430.87 which represents a decrease of 10% approximately and the average yield price has increased from $1153.24 to $1407.65, which represents an increase of 22% approximately.

Another experiment was conducted in the year 95/96 in 32 fields in Noubaria, Gemeiza, and Sharkia for the same purposes mentioned here above. 16 fields were managed using NEPER and the other 16 were managed in the traditional way. In this experiment we used only the diagnosis and treatment subsystem and hence the impact is only due to this subsystem. The average yield price of feddan has increased from $503.99 to $638.25 which represents an increase of 27% approximately. The average treatment cost price has increased from $27 to $35.35 which represents an increase of 31%. However, if we take the difference between the yield price and the treatment cost price, we will find that the net production in dollars of the control field is $476.99 and the net production of the expert system field is $602 which represents an increase of 26.4%.

Environmental Impact

The CUPTEX experiment showed that less pesticides and fertilizers were used. Hence better environment conservation has been achieved. Although our initial strategy was optimizing the economic aspect of the agricultural process, we get an agricultural practice, which is less harmful to the environment. Using the cost as indicator of the increase or decrease of using the pesticides and chemical fertilizers, we found that the overall usage of fertilizers has decreased from $139.84 to $104.86, which represents a decrease of 25 % approximately. The usage of pesticides has also decreased from $339.11 to $ 326.01 which represents a decrease of 4 % approximately. This reduction in using chemicals did not affect the yield. If we take the ratio between the total cost of the chemicals used and the yield price, we will find that this ratio has decreased from 0.415 to 0.306 with a percentage decrease of 26 % approximately. This decrease can be interpreted as the decrease in the chemicals used to produce the same yield.

Another aspect of environment is the efficient usage of water. The results showed that more water was used in the expert system tunnel, 229.85 m^3, than the control tunnel, 213.14 m^3. As the water is not priced in Egypt, we did not add it to the cost. If this quantity is divided by the yield price for the expert system and control tunnels respectively, we will get the amount of water used for producing $1 value of cucmber. These amounts are 0.16 m^3 and 0.18 m^3 for expert system and control tunnels respectively. This means that we get a saving of approximately 11% of the water used to produce the same quantity of cucumber under plastic tunnels.

As concerning NEPER, there was an increase of 31% in using chemicals in the expert system fields. However if we take the ratio between the treatment cost and the yield price we will find that this ratio has increased from 0.054 to 0.055 with a chemical percentage increase of only 1.85%and not 31%. This increase can be interpreted the increase in the chemicals used to produce $1 value of wheat.

Human Resources Development Impact

In order to measure the effectiveness and impact of expert system on human resources development, we conduct an experiment to compare the performance of extension workers before and after training courses on the usage of expert systems. 11 extension workers specialized in protected cultivation and 8 extension workers specialized in horticulture participated in this experiment. Sets of cases covering the different aspects of CUPTEX and CITEX were prepared and distributed on trainees before training. The trainees were asked to give their decision which is an irrigation schedule, a fertilization schedule, symptoms to be observed if a disorder is suspected or treatment schedule. After the trainees had submitted their solved cases, the training on the usage of expert systems was conducted. The same cases were distributed again and then evaluated. The results showed that the overall performance enhancement of protected cultivation extension workers was approximately 100% and the overall performance of horticulture extension workers was approximately 579% (Rafea and Shaalan, 1996)

In the NEPER field experiment, we also measure the difference in advice given by extension workers using the system and those who are not using it. We found that the percentage of matching between advice produced by NEPER and extension workers advice was only 44.3%. This means that the extension worker performance can be enhanced by approximately 125% if they use the system.

Conclusion

The objectives of the research program were successfully achieved. The proposed methodology was tested in the development of the four expert systems. The fifth expert system, NEPER, used the generic task methodology. The developed tool, KROL, was tested in the implementation of the three expert systems for cucumber, tomato, and orange. NEPER was implemented using a tool developed by Michigan State University on top of Small Talk programming language. LIMEX was developed using the commercial shell CLIPS. The five expert systems were evaluated and proved to be competent to human experts. The systems were deployed and their impacts were measured. The experiments conducted on cucumber and wheat showed that using expert systems has a positive economic impact. The conservation of environment was also observed in the recommendations generated by the expert systems. The performance of extension workers was enhanced after being trained on using the systems. The usage of the expert system as a decision support tools raises the performance of extension workers to the level of experts in every agricultural discipline.

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Table-1 The subsystems included in each of the five expert systems developed

	Site Assessment	Seedling Production	Cultivation Preparation	Agriculture Practice Management	Disorder Diagnosis and Treatment	Ratio of ES Performance to a Human Expert
Cucumber	Not Included	Separate (RB) (EXSYS)	Included (KADS) (KROL)	Included (KADS) (KROL)	Included (KADS) (KROL)	1.04
Tomato	Not Included	Not Included	Not Included	Not Included	Included (KADS) (KROL)	1.04
Orange	Included (KADS) (KROL)	Not Included	Not Included	Included (KADS) (KROL)	Included (KADS) (KROL)	1.08
Lime	Included (KADS) (CLIPS)	Not Included	Not Included	Included (KADS) (CLIPS)	Partially (KADS) (CLIPS)	1.37
Wheat	Not Included	Not Included	Included (GT) (Small Talk)	Included (GT) (Small Talk)	Included (GT) (Small Talk)	0.98

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