Natural Resources Conservation and Crop Management Expert Systems

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Abstract: This paper presnts how expert systems for crop management can help in natural resources conservation. This is done through giving an overview of the status of natural resources in Egypt with emphasis on water and soil resources , describing briefly five expert systems developed for managing cucumber, tomato, orange, lime, and wheat, and explaining how the recommendations that optimize the output relative to the agricultural inputs will lead to environmental conservation as it will be guaranteed that no extra inputs will be provided such as water, fertilizers and pesticides without a return in the yield. The paper also responds to the issue concerning the integration with other types of software and presents how decision makers at different levels can use crop management expert systems.

1. Introduction

This paper describes a case study in developing Crop Management Expert Systems and how this relates to the soil and water conservation. The paper consists of 5 sections. The first section gives an overview of the status of natural resources in Egypt with emphasis on water and soil resources. The second section describes briefly the five expert systems developed so far for managing cucumber, tomato, orange, lime, and wheat. The third section discusses how using these expert systems will help in conserving water and soil. The fourth section responds to the issue concerning the integration with other types of software. The fifth section presents how decision makers at different levels can use crop management expert .

2. The Natural Resources

The conservation of natural resources has two aspects. The first is pertinent to the management of these resources on the macro level, such as controlling the expansion of urban development in order no to loose agricultural land. The second is concerned with the management of these resources on the micro level such as adding chemical fertilizers to the soil. In the following subsections, we shall consider only the status of the water and land resources because they are the two main resources related to our work on crop management expert systems.

2.1 Water Resources

Water is the most scarce resource in Egypt, since its supply is nearly fixed and water demand for different sectors is continuously increasing. The water supply can be classified into three categories: surface water, ground water, and waste water reuse after treatment either from agriculture drainage or domestic usage.

The River Nile is the principal source of surface water, since it provides Egypt with more than 95% of
is 55.5 billion m^3 .

There are two sources of ground water in Egypt. The first is the valley and Delta ground water. This is not an additional resource since it is recharged by the Nile and excess irrigation water. The total storage of its aquifer is about 500 billion m^3 with an average salinity of 800 ppm. The annual rate of abstraction of groundwater for domestic, industrial, and agriculture use was estimated at 2.6 billion m^3 in 1990. The second ground water source is the non-renewable deep desert ground water. The major part of this source comprises the aquifer in the western desert. Preliminary estimates indicate the total ground water storage in the western desert is about 40,000 billion m^3 with salinity varying between 200 and 700 ppm. Ground water is also available in numerous aquifers in Sinai, but there is less information about them. The extraction rate from deep desert ground water in 1990 was estimated at 0.5 billion m^3.

The portion of drainage water reuse depends on the quality of drainage water in terms of its salinity and contamination from municipal, industrial, and agricultural effluents. The amount of drainage water reuse in 1990 for irrigation was estimated at 4.9 billion m^3.

The decision-makers concerned with water resource management in Egypt are challenged by how to balance the limited water supply with an increasing water demand for the future, since water is the major constraint for land expansion to satisfy food self-sufficiency. The expected water demands for year 2000 are 69.4 billion m^3 whereas the expected water resources are 74.0 billion m^3 taking into consideration the usage of agricultural drainage water, treated municipal sewage water, and ground water. Another challenge is how to reduce the water pollution resulting from using chemical fertilizers and pesticides.

2.2 Land Resources

After water, land is the major limiting factor for sustainable agricultural development. The total cultivated land in Egypt is about 7.4 million feddans (1 feddan = .42 hectare = 1.04 acres) or only 3% of the total land area. Due to the arid climate, agriculture relies mainly on irrigation by River Nile water. Most of these lands are concentrated in the Nile Valley and Delta regions. The areas lying outside the Nile basin - oases of the New Valley and Mediterranean coastal plains including Sinai - are partly rain fed or irrigated with ground water. Cultivated lands in Egypt are classified into two categories: Old Land and New Land. Old Lands, refers to lands along the Nile Valley and Delta regions that are irrigated directly from the Nile . These lands have been under irrigation for a long period of time. It is very fertile and its soils are alluvial silt and clay loam. New Lands, are the less fertile desert areas outside the Nile valley, where the soils are generally sandy and calcareous. The New Lands are distributed west of the Delta (Nubaria), east of the Delta (Salhia and along the western side of the Suez Canal), Sinai, and in the New Valleys of the Western Desert. The estimate for Old Land is about 5.4 million feddans and about 2 million feddans for the New Lands reclaimed since 1952.

The issues of old agricultural land losses, either in quantity (land withdrawn to non-agricultural use) or quality (land quality degradation is mainly due to soil salinization and water logging because of an inefficient drainage system) and limitation of water resources for expanding the land area are the major constraints for sustainability of land resources and consequently satisfying food self-sufficiency for the growing population.

3 Crop Management Expert Systems

The expert systems being developed are mainly for crop management. The focal point of these development efforts is the Central Laboratory for Agricultural Expert Systems (CLAES) within the Agriculture Research Center (ARC), Ministry of Agriculture and Land Reclamation (MOALR). Five expert systems are currently being developed for five crops : Cucumber, Orange, Wheat, Tomato, and Lime. The following subsections describe the components or subsystems common to crop management expert systems namely: Site Assessment, Seedling Production, Cultivation Preparation, Agriculture Practice Management, and Disorder Diagnosis, and Remediation.

3.1. Site Assessment

This subsystem was developed for Orange (Salah,Rafea,Mohamed 1992). The function of this subsystem was to generate one of these decisions: the site is perfect for cultivation, a set of treatment operations has to be applied before cultivation, it is feasible to cultivate but you have to follow a set of recommendations, or the site is not suitable for cultivation.. This subsystem is very useful to be executed before any consultation because if a plantation is not suitable for cultivation, there would be no need to go to any other subsystem like diagnosis, for example. This subsystem was developed using NEXPERT/Object (Nexpert,1988). An Arabic version was also developed for this subsystem.

3.2. Seedling Production

This subsystem was developed for Cucumber seedlings (Rafea, Warkentin,Ruth,1991), (El-Dessouki,et al,1991), (El-Dessouki, Rafea, Youssef,1992). It has six functions: seeds cultivation, media preparation, environmental growth factors control, diagnosis, treatment, and protection. This subsystem was developed using EXSYS shell (EXSYS,1989).

3.3. Cultivation Preparation

This subsystem was developed for Cucumber (Rafea,et al,1992), and another one was developed for Wheat (Kamel,et al,1993). The main objective of these subsystems is to give advise concerning the pre-cultivation activities in the production stage. The outputs of this subsystem are a set of agricultural operations. Some of these operations are special to a specific situation, and the others are routine operations. However, the explanation of these routine operations was found very useful for novice growers. The subsystem developed for Cucumber used NEXPERT/Object shell (Nexpert,1988) whereas the one for Wheat was developed using routine design generic task using the programming language Small Talk (Kamel,et al,1993).

3.4. Agriculture Practice Management

This subsystem was developed for Cucumber , and Orange (Salah,et al,1993). Two other subsystems are currently being developed for Wheat (Kamel,et al,1993), and Lime . The main objective of such systems is to generate an irrigation, fertilization, and preventive operations schedules. The irrigation and fertilization schedule includes the water quantity, irrigation interval, nutrient quantity, and application interval. These outputs are based on quantitative reasoning rather than heuristic reasoning. The preventive operations schedule includes the preventive operations such as agriculture practices operations, and preventive chemical spraying. The two subsystems for Cucumber, and Orange were developed using NEXPERT/Object shell (Nexpert,1988), and currently are being transferred to a knowledge representation language based on objects and logic paradigm. This language was developed in CLAES (ESICM,1992).

3.5. Disorder Diagnosis & Remediation

This subsystem was developed for Cucumber (El-Dessouki,Edrees, El-Azhari,1993), and currently is being developed for Orange, and Wheat. The main objective of this subsystem is to identify the cause of an observed disorder, its severity, and then propose the appropriate remediation. The user can consult directly the remediation part if the cause of the disorder is known for him. However the remediation part, in this case, verifies the cause given by the user before giving the remediation advise. The subsystem for Cucumber was implemented using KROL (ESICM,1992).

4. Effect of Using Expert Systems on Water and Soil Conservation

This section describes how the usage of expert systems can contribute to the water and soil conservation. As mentioned hereabove , there are two problems facing decision makers to conserve water resources namely: the efficient utilization of water resources, and the pollution resulting from the usage of chemical fertilizers and pesticides. Regarding soil conservation, there are two main problems namely: the urban expansion, and the soil degradation resulting from excessive use of fertilizers and other bad agricultural practices.

Therefore, the main contribution of expert systems for soil and water conservation is to transfer the agricultural practices according to certain strategy or a combination of strategies namely : environmental sustainability, economical sutaniability and/or social sustainability. In the expert systems we have built so far , we were concerned with economic sustainability taking into consideration the environmental sustainability in the second place. In otherwords, we were trying to acquire the recommendations that optimize the output relative to the agricultural inputs. As a consequence, environmental conservation will be achieved as we will guarantee that no extra inputs will be provided such as water, fertilizers and pesticides without a return in the yield.

In order to evaluate the systems, an evaluation methodology was applied by generating typical cases and distribute them to three domain experts in a certain specialty. Each subsystem is related to more than one specialty. For example in the remediation subsystem, we have three specialties: plant pathology, entomology, and nutrition. Therefore 9 experts have participated in the validation of this subsystem. For each specialty, an evaluator was selected to blindly asses the responses of the three human experts and the expert system . After the evaluation took place, the domain expert participated in the development, the evaluator, and the domain experts participated in the evaluation met together

with the knowledge engineer to discuss the evaluation results till they reached to a consensus. The scale used for the evaluation was 3 for excellent, 2 for good, 1 for acceptable, and 0 for unacceptable.

The scores shown in Figure-1 are the total scores of groups of experts divided by the total number of cases of each subsystem. of one of the expert systems we have developed for cucumber under plastic tunnels (CUPTEX) (Rafea et.al., 1995) . CUPTEX is not a single expert, it is in effect a group of experts. Experts group-1 score is the score of the best expert in each specialty, experts group-2 score is the second best, etc..

As we can see from figure-1 the maximum score does not reach excellent. That is because the group decision is better than individual decisions. We can also notice that CUPTEX over performs human expert in two subsystems, and its score in the third one is 0.75 of the best experts-group. CUPTEX can be trained to reach excellency, and this is currently be done.

Even with this performance, the field test proved that it is very useful in reducing cost, and increasing yield as is shown in figure 2 which represents the results of experiments conducted in two sites: El-Bousily, 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 or any specialist, and the other one was to be cultivated as usual, this is a control tunnel. The results of the two sites gave positive results in favor of using the field prototype.

As we can see from that experiment that CUPTEX has over performed the human experts and hence if we build it according to any strategy, we can disseminate this strategy nation wide very effectively.

The second outcome of this experiment was that less pesticides were use and hence better environment conservation 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.

The third comment that we can notice is that although more fertilizers and water were used, the yield was more than the control tunnel. If we trained our expert system to give highest priority to the environment, then different results could be obtained. However the difference noticed between the expert system tunnel and the control tunnel is not significant. This experiment is being repeated in different sites to get more reliable results.

5. Impact of Deploying Cucumber Expert Systems

The development of such expert system aims at giving the farmers good service at the extension offices, as part of the mission of MOA, and hence the national production will increase and environment will be conserved. This will lead indirectly to paying off the development cost. However, the application payoff can be measured in terms of the increase of cucumber yield and the reduction of production cost in the research locations where cucumber is cultivated for experimentation, within MOA as this yield of these locations is sold. Another measurement of the application payoff is the decrease in using chemicals and hence conserve environment which is the main issue of this paper.

During the last year, experiments were conducted in six sites: El-Bousily, El-Noubaria, Toukh, El-Haram, El-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 or any specialist, and the other one was to be cultivated as usual, this is a control tunnel. The results have been found positive in favor of using the field prototype.In this paper, we will present the results related to using chemical which affects the environment. We have used the cost in order to sum up all the fertilizers and pesticides used, otherwise we should give a diagram for each chemical as it does not make sense to add the quantities of different chemicals. The cost is an indicator of the increase or decrease of using the chemicals in general. Figure 2 sumarizes the results. It should be noticed that the overall usage of fertilizers has decreased from LE475.46 to LE356.52 which represents a decrease of 25 % approximately and the usage of pesticides has decreased from LE 1152.99 to LE 1108.44 which represents a decrease of 4 % approximately. If we take the total cost, we will find that it has decreased from 1628.45 to 1464.96 which represents a decrease of 10% approximately. This reduction in using chemicals did not affect the yield but in contray, the yield price has increased from LE 3921 to LE 4786 which represents an increase of 22% approximately. If we take the ratio between the total cost of the chemicals used and the yield, price we can find that this ratio has decreased from 0.415 to 0.306 with a percentage dencrese of 26 % approximately. This decrease can be interprted as the decrease in the chemicals used to produce the same yield.

As the water is not priced in Egypt, we could not add it to the above diagram. Fig. 3 depicts the water utilization quantities in both the expert system tunnels.and control. If this quantity is divided by the yield in kilograms which was 6198 and 5174 for the expert system and control tunnels respectively, we will get the amount of water used for producing 1 kilogram. These amounts are 0.037 m^3 and 0.04 m^3 for expert system and control tunnels respectively. This means that we get a saving of approximately 8% of the water used to produce the same quantity of cucumber under plastic tunnels.

6. Integration of Expert Systems with Other Software

6.1. Integration with GIS

Although in Agricultural Expert Systems and DSS the interface with GIS provide a good visualization, our expert systems has no interface to a complete GIS package using sophisticated user interface like ARC/INFO or any other ready made GIS supportive environment. It has an interface to a simple data base that includes necessary data for soil, water and climate. This database is not complete, we incrementally add data whenever necessary, i.e. when the system is to be delivered to a new location.

We are aware that integrating ES with GIS will provide good visualization, but we have been faced with three problems:

1) The high price of GIS package
2) The problems we will face when integrating our expert system developed in Prolog
3) The runtime license for the GIS package.

Our system is made to be given to the extension offices and to growers free of charge at the beginning for testing and evaluation. We could not afford to do that if a ready made package is purchased. Therefore we are intending to investigate building our GIS package with the customized limited facilities to suit our application in the future.

6.2. Integration with Data Base

Data Base technology is one of the fields that extensively makes use of computers. It is the heart of any information system to be developed within any organization. In agriculture, information systems have been used, as in any other discipline, in management, research, finance, and other areas. At some sites where expert systems may be needed, information system may be there before. Therefore, it may be necessary to integrate the expert system with the working environment, especially if the data needed by the expert system is part of an existing data base. If there is no previous information system within any location, we found that expert systems need data base to store static data of a specific plantation in order to be used by the inference engine of the expert system, otherwise the system has to ask the user each time he/she runs the system to enter these data. For sure, this is inconvenient to the user who is, in our system, the extension worker giving advises to several growers who may have more than one plantation. Although one may claim that this problem can be solved by simply keeping these data on a file and retrieve them when needed, this claim is untrue because managing the set of files for all plantations, memorizing the name of each plantation file, maintaining the integrity of the knowledge base with the data base, and other reasons require the usage of a knowledge and data bases management system.

6.3. Integration with Simulation Models

Simulation models have been used in agriculture long before using expert systems. There are different types of models: crop growth models, pest models and others.

In one of our expert systems, we have been interested in integrating a wheat expert system with a simulation model for wheat CERES (Richie et al, 1985). We find out that the integration could serve in predicting the yield given the outputs of the expert system as input to the simulation model.

6.4. Integration with Multimedia

The need for integrating expert systems with multimedia will be done through discussing where each multimedia type could be used to enhance the utilization and performance of the expert system. Providing explanations during consultation and/or after reaching a conclusion can also be enhanced using all types of multimedia.

It was found that describing symptoms in words is very difficult and sometimes is very confusing. Therefore, images are identified to be used for two main purposes: describing a disorder symptom, and confirming the diagnosis of the cause of a certain disorder. Detailed images for all symptoms, and unique images that confirm the occurrence of disorders at different stages should be collected. Although images are very useful in acquiring the user inputs, the uncertainty problem is still there. Therefore, giving the user the option to select an image with a degree of certainty should be provided. Providing more than one picture for the same symptom can reduce the user uncertainty, but this will lead to exerting more efforts in collecting and classifying the images.

As already explained, the output of an expert system for crop production management, is a set of agricultural operations. Describing how to perform an agricultural operation in words, is very hard and one can never guarantee that the user can understand what has been written. Displaying a video for a professional doing the recommended operation would be very informative.

The sound is essential because sometimes, it is not easy to write terminology used by growers in daily life. In addition, combining the video with sound is also recommended to comment on how the operation is done.

7. Decision Makers as Expert Systems Users

The developed expert systems can be used by decision makers at different levels: operation level and planning level.

On the operation level, the extension workers in the village, district, and/or governorate can use the system to support him in making his decision in giving the appropriate advice to the growers.

On the planning level, the decision makers can use the expert system to predict the needs of water, fertilizers, and pesticides for a given crop in the region given the area cultivated in such a crop. This generated information is very important for different users: the traders, the exporters, the importers of these materials. The top level management at the Ministry of Agriculture are also interested in this type of information to plan for the crop rotation cycle and measure the inputs and outputs for each crop. Another type of application is the estimation of the yield given a simulation model linked with the expert system. The prediction of yield can serve the decision makers in deciding the amount to be imported in advance, if any, and hence take necessary actions.

8. Conclusion

There is a local R&D effort going to develop more expert systems for other commodities in addition to maintaining the developed ones. Continuous research are being conducted to enhance the tools we have developed and also enhance the knowledge base and interfaces of the expert systems. A specialized Lab. has been institutionalized within the Agriculture Research Center to be responsible for providing the extension services, and growers with computerized packages (expert systems) to be used in addition to the manual package provided by the research centers. This specialized Lab is called Central Lab. for Agricultural Expert Systems.

Our current users are the extensionists and growers. Right now we have five systems deployed in 16 locations. The studies so far proved that using the expert systems in cucumber production under plastic tunnel has increased production and in the mean time reduced the usage of pesticides.

The Hardware used in our study was 486 based machine running DOS, and Windows. We used different languages and tools. The programming languages we used are Prolog, C, C++, and Small Talk. The tools used are EXSYS, NEXPERT/OBJECT, LEVEL5, and CLIPS which are expert system shells. All commercial shells except CLIPS, need a runtime license for expert systems developed on top of them. Therefore, we ended to use our own shell developed on top of Prolog. The problem we faced is the user interface and data base interface development. The user interface was solved by developing it in C and liked to Prolog. The database interface was firstly solved in the same way but later on we used the database of Prolog itself. The Prolog we are using , SICSTUS, is not running in Windows environment and this is causing a problem right now in porting the expert systems developed to run in a window environment which becomes a de facto standard. However, the SICSTUS developers announced that it will be available soon on Windows.

Expert systems for crop management can be used as decision support tools at different decision makers levels. They are now used by the decision makers at the operation level and we are planning to let them be used at the planning level .

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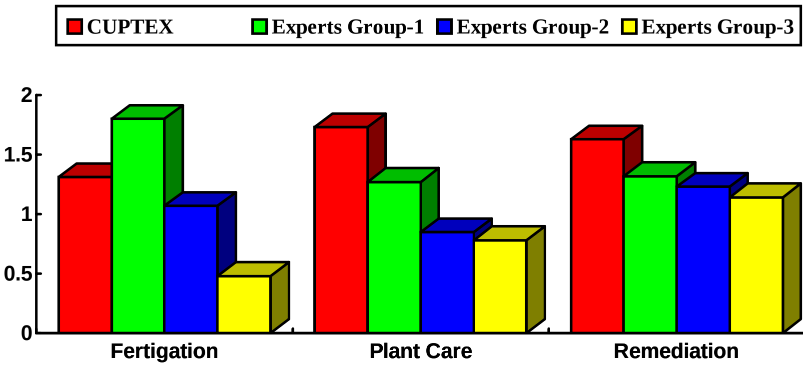

Figure-1 Evaluation Results

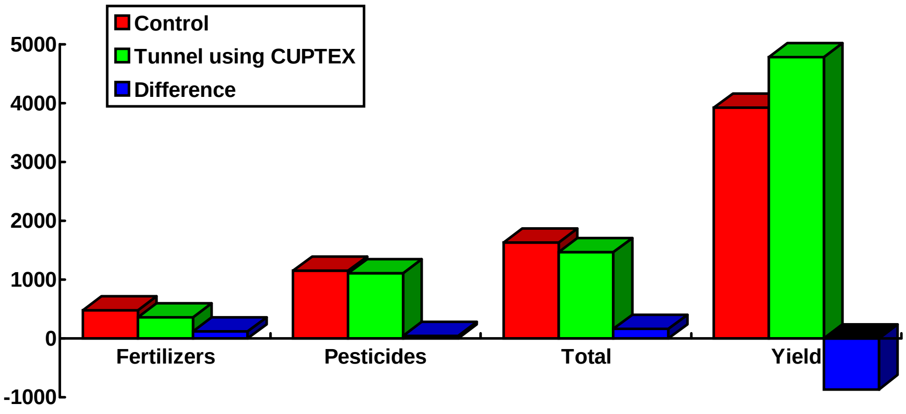

Figure-2 Average Cost of Chemicals Used and Yield for one Tunnel (L.E.)

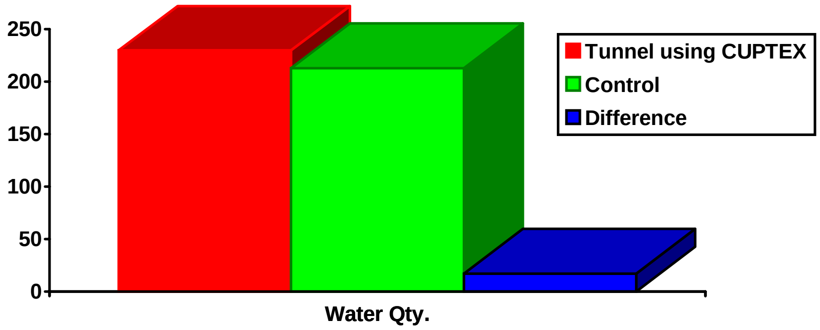

Figure-3 Average Water Quantity for one Tunnel (m3)