Expert system for scheduling supplemental irrigation for fruit and vegetable crops in Ontario

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Clarke, N.D., Tan, C.S. and Stone, J.A. 1992. **Expert system for scheduling supplemental irrigation for fruit and vegetable crops in Ontario**. Can. Agric. Eng. **34**: 027-031. An expert system has been developed to schedule supplemental irrigation of fruit and vegetable crops in Ontario, a sub-humid region. Equations and heuristics are both used to reproduce the expert's method for predicting irrigation dates and determining the amount of irrigation water to apply. The test results show the expert system consistently matches the recommendations made by experts.

Key Words: expert systems, irrigation scheduling

Un système-expert a été développé pour contrôler l'irrigation d'appoint des fruits et légumes en Ontario (une région sous-humide). La méthode du système pur prédire les date d'irrigation et la quantité d'eau à appliquer est basée sur des équations et heuristiques. Les résultats des tests démontrent que le système-expert est conforme aux recommandations faites par les spécialistes.

INTRODUCTION

Ontario is a sub-humid region that has much potential for crop production. However, during the summer months irregular and inadequate rainfall can cause water shortages and reduce crop yield, quality or both (Fulton and Tan 1986). Supplemental irrigation is starting to become an attractive alternative on fruit and vegetable fields in Ontario as growers attempt to optimize crop growth and production. Interest in irrigation has also increased as a result of the drier than normal years of 1985, 1986 and 1988. At the present time, few producers irrigate and almost none are familiar with irrigation scheduling methods.

The majority of vegetable and tree fruit crops are grown on Ontario's course-textured soils with low water storage capacities. Irregular water supply has been shown to reduce growth and yield of many crops grown on the sandy soils at Harrow. Irrigation of pickling cucumbers increased the marketable yield by 30% to 272% relative to non-irrigated cucumbers (Tan et al. 1983). During an 11 year period, irrigated peaches consistently produced the highest annual marketable yield and had a tree survival rate of 95% compared to 56% for non-irrigated peaches (Layne and Tan 1984). Between 1985 and 1988, irrigated tomato yields were 4.5 to 21.6 t/ha greater than non-irrigated tomatoes (Tan 1990). During an 11-year period in southern Ontario, the average increase in yield of early potatoes due to irrigation was 8 t/ha (Fulton and Tan 1986).

To obtain the maximum benefit from irrigation, the water must be applied at the most appropriate times and in the required amounts to both prevent excessive moisture stress and to avoid water waste and nutrient leaching. In humid and sub-humid areas such as Ontario, greater variability in crop evapotranspiration and rainfall distribution necessitates irrigations at more irregular intervals than in arid areas (Tan 1988; Lambert et al. 1981).

Computer programs have been used in arid, semi-arid and humid regions to estimate crop evapotranspiration (ET), calculate water budgets, and schedule irrigation for various crops (Camp et al. 1988; Cassel et al. 1985; Couch et al. 1981; Hobbs and Krogman 1983; Hook et al. 1984; Kanemasu et al. 1978). The computer models generally schedule an irrigation event to occur when the estimated available soil moisture in the rooting layer is depleted to a certain level. Crop ET is usually estimated by multiplying a crop coefficient by a reference ET that is calculated from weather data.

Several factors limit the application of traditional computer programs to irrigation scheduling in Ontario. First, there is a lack of data for crop coefficients and crop rooting depths for the Ontario soils and climatic conditions. Also, there is a great variation in the type of climatological data measured at local weather stations. For example, radiation is measured at about 25 stations in Canada and daily bright sunshine hours at about 208 stations (Tan 1980). With irrigation scheduling in Ontario, consideration must be given to the availability of data, ease of computation and reliability of results over a wide range of climatic conditions (Tan 1980). Finally, because irrigation is only starting to become widely used, irrigators in Ontario are inexperienced and unfamiliar with irrigation scheduling principles.

Knowledge-based systems and concepts have advantages over conventional programming techniques as knowledge-based systems allow for detailed explanation of reasoning procedures, utilization of incomplete and uncertain data, and utilization of experiential knowledge (Waterman 1986). Knowledge-based systems and expert systems (ES) are being used in agriculture to solve problems characterized by incomplete data and heuristic data (Clarke et al. 1990; Halterman et al. 1988) and also to train and educate individuals to solve new tasks (Engel and Beasley 1987).

The objective of the study reported here is to develop a knowledge-based system for irrigation scheduling in Ontario (IRRIGATOR). The knowledge-based approach incorporates heuristics (rules of thumb) as well as mathematical algorithms to forecast irrigation dates and recommend application amounts.

MATERIALS AND METHODS

The method used to develop the knowledge base for IRRIGATOR is the same as outlined by Waterman (1986) and used by Halterman et al. (1988). The five stages of the method are identification, conceptualization, formalization, implementation, and testing. Because the method is an iterative process that relies on the refinement and expansion of a prototype, the stages are not clearly separable but are highly interrelated and interdependent (Jones and Barrett 1989).

During the identification stage, the expert, knowledge engineer, and end user (a novice irrigation scheduler) were identified. The domain expert is Dr. C.S. Tan, irrigation specialist at the Agriculture Canada Research Station, Harrow, Ontario. The problem was defined as scheduling the timing and amounts of irrigation for fruit and vegetable production in Ontario. The software must also provide sufficient explanation of the scheduling process so that the user can learn the fundamentals of irrigation scheduling. The personal computer was chosen as the delivery platform since it is the most accessible to the end user.

During the second stage, the key concepts, relationships, solution strategies, and information flow were identified. Two major tasks were identified: initialization of the knowledge base (to occur once a year, at the beginning of the irrigation season), and prediction of the next irrigation date and knowledge base updating (to occur on a daily basis). Relationships between weather, weather forecasts, crops, soil, and soil moisture were identified. The important parameters necessary to describe the above concepts were also identified.

In stage three, the knowledge was formalized by structuring it into a rule-based format to be used within an ES-building tool. Rules were written to describe the concepts and knowledge resulting from stage two. The rules were loosely structured into groups or frames (Fig. 1). Each group of rules solves a particular sub-goal of the irrigation scheduling problem.

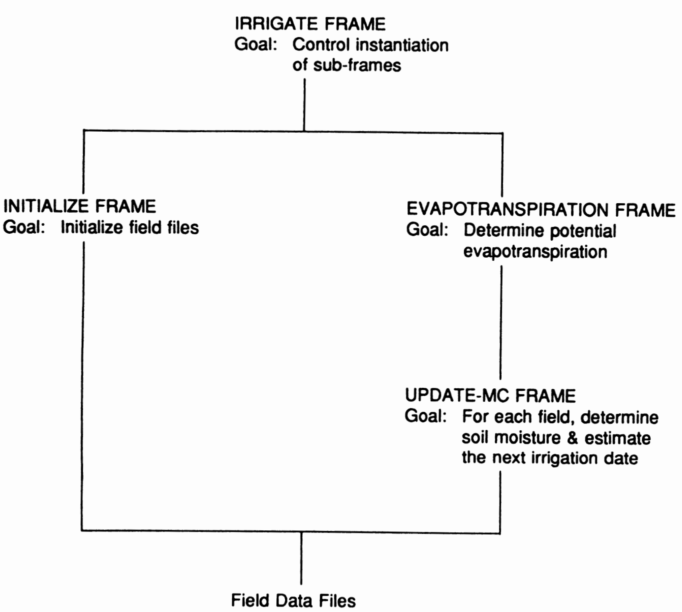

Fig. 1. Knowledge structure of IRRIGATOR.

For the implementation stage, a prototype ES was developed by programming the formalized knowledge into the computer. The prototype was developed on an IMB AT compatible with Personal Consultant™ Plus[1], a production system development tool.

During the final stage, the knowledge base and control structure were tested, evaluated and revised. Each rule and rule group were tested to ensure that it accurately and consistently represented the expert's knowledge. Test cases were used to ensure that the control strategies were correct and that the appropriate rules executed given the current facts. When errors were found they were corrected immediately and the rule base was tested again. The testing stage overlapped considerably with the formalization and implementation stages as each rule was tested when it was implemented. On several occasions when errors were detected, parts of the problem had to be reformalized and implemented.

RESULTS AND DISCUSSION

The knowledge in IRRIGATOR is structured into frames (Fig. 1). The root frame, IRRIGATE, contains general knowledge about the irrigation such as the appropriate method for estimating potential ET. IRRIGATE also controls the instantiation or activation of the sub-frames INITIAL and EVAPOTRANSPIRATION when the knowledge and information they contain is required.

During a consultation, the frame INITIAL is instantiated only if field files are not present. The field files contain information (name, crop, soil texture, soil moisture level, field capacity, wilting point, required irrigation) for each field. The goal of INITIAL is to initialize the field files at the beginning of the irrigation season. (In Ontario, the irrigation season generally runs from late May to the end of August). Some of the information, such as field name, crop, and soil texture is entered directly by the user. Other required data can either be entered by the user or, if unknown, estimated by rules in the INITIAL rule base. For example, the initial soil moisture level can be directly entered by the user, calculated from oven dried samples, estimated based on the date of the last rain, or estimated by the feel method.

The EVAPOTRANSPIRATION frame contains global knowledge and climatological data that apply to all irrigated fields. The climatic data required to estimate the potential ET are entered by the user. The EVAPOTRANSPIRATION frame estimates the potential crop ET by one of four methods: Class A pan evaporation, Penman model, Priestly and Taylor model, or default values for Ontario. The actual method will depend on the availability of climatic data from local Ontario weather stations. Both the Penman, and Priestly and Taylor model require net radiation data (Fig. 2). Rules are available so that net radiation can be directly entered or estimated from either downward solar radiation or the number of hours of bright sunshine. If the user does not have the climatic data readily available, default values are used based on historical averages.

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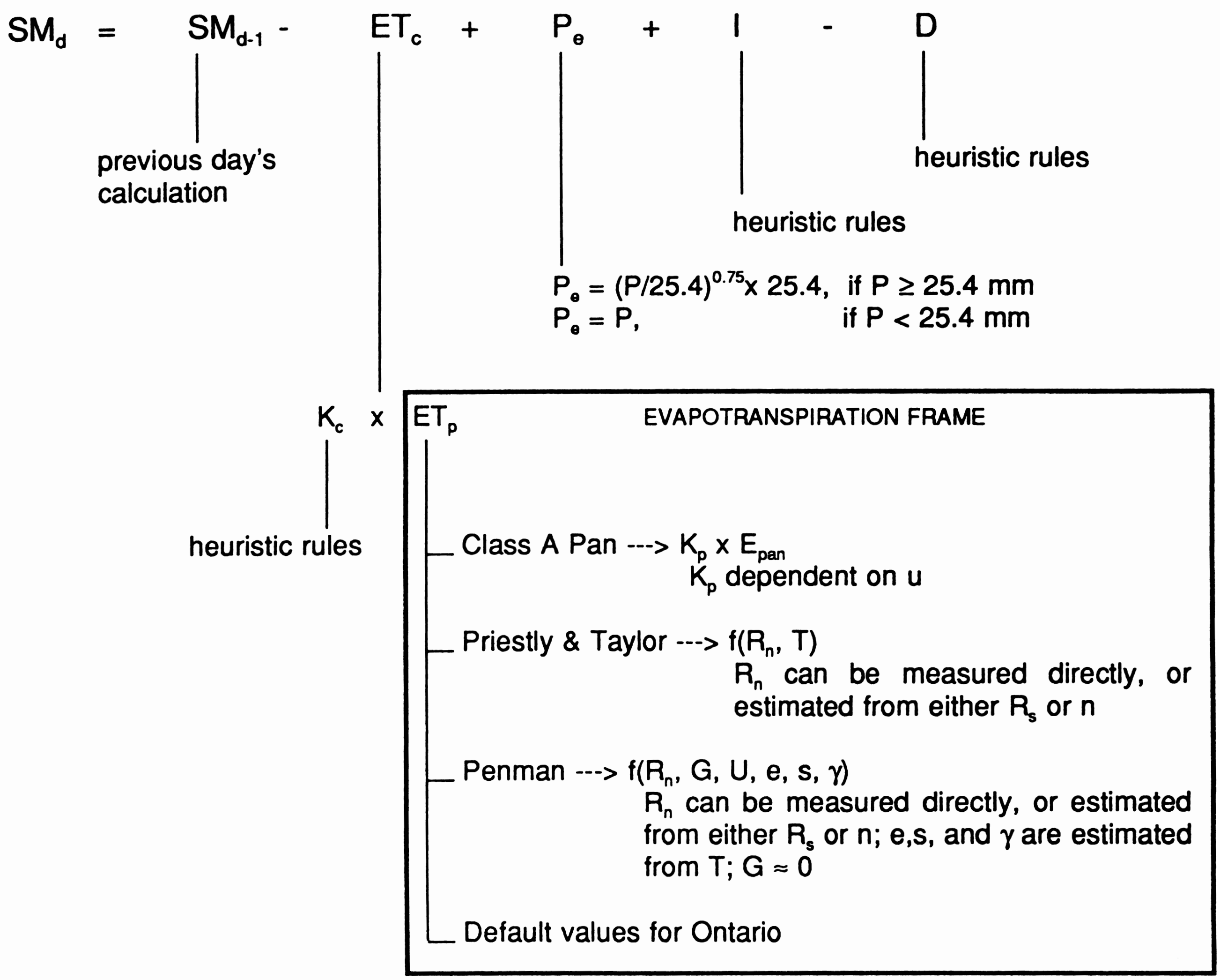
[1]Trade and Company names used in this report are solely for providing specific information. Their mention does not constitute a guarantee of the products or an endorsement over other products not mentioned. Personal Consultant is registered trademark of Texas Instruments.



SM_d - soil moisture in the rooting layer (mm) on day d
SM_{d-1} - soil moisture in the rooting layer (mm) on day d-1
ET_c - crop evapotranspiration (mm)
P_e - effective rainfall (mm)
I - irrigation (mm)
D - drainage below the root zone (mm)
P - actual precipitation (mm)
K_c - crop coefficient
ET_p - potential evapotranspiration (mm)
K_p - pan coefficient
E_{pan} - pan evaporation (mm)
u - total wind movement (km/day)
R_n - net radiation (MJ/m^2)
T - temperature (C)
R_s - solar radiation (MJ/m^2)
n - hours of bright sunshine
G - soil heat flux (MJ/m^2)
e - saturation vapour pressure (mb)
s - slope of saturation vapour pressure curve (mb/C)
γ - psychrometric constant

Fig. 2. Sources of knowledge used to solve for soil moisture.

It is not recommended that default values be used throughout the irrigation season but only if data are unavailable for one or two days. The EVAPOTRANSPIRATION frame is instantiated for each day that has passed since the field files were last updated. The EVAPOTRANSPIRATION frame also instantiates the UPDATE-MC frame for each field that is to be irrigated.

The UPDATE-MC frame is instantiated for each field, where a field is an area of land that either has a different crop or a different soil texture than other fields. UPDATE-MC uses both heuristics and equations to mimic the expert's method for scheduling irrigation requirements for each field. Soil moisture levels are estimated using the generalized equation which has been used successfully for corn (Kanemasu et al. 1978), tomatoes (Tan 1988) and peaches (Tan and Layne 1981):

$$SM_d = SM_{d-1} - ET_c + P_e + I - D \quad (1)$$

where:

SM_d, SM_{d-1} = soil moisture in the rooting layer on day d and d-1 respectively, (mm)

ET_c = crop evapotranspiration (mm),

P_e = effective rainfall (mm),

I = irrigation (mm), and

D = drainage below root zone (mm).

Figure 2 shows how different sources of knowledge are used to solve the equation. The following example shows how heuristics are used to solve for irrigation, I:

IF the available soil moisture is between the 50% level and the lowest allowed level (40% for heavy soils, 45% for light soils) AND
there is a 60% chance of rain within the next 2 days
THEN irrigation amount = 0

IF the available soil moisture is less than the lowest allowed level (40% for heavy soils, 45% for light soils) AND
there is a 60% chance of rain within the next 2 days
THEN irrigate to bring the available soil moisture to the 75% level

IF the available soil moisture is less than the 50% level AND
the chance of rain within the next 2 days is less than 60%
THEN irrigate to field capacity

Once the soil moisture level has been determined, the next irrigation date is predicted. The crop ET from the previous 5 days is used to forecast when the available soil moisture will fall below the 50% level. The UPDATE-MC frame also contains a plotting routine to display a graph of the history of the available soil moisture in each field (Figs. 3 and 4). Finally, the UPDATE-MC frame updates the values of soil moisture level and required irrigation in the field files.

IRRIGATOR was extensively tested and validated during the development process. To illustrate the performance of IRRIGATOR, climatic data for peach in 1983 and tomato in 1987 were used to predict irrigation dates. In both studies, hours of daily bright sunshine and daily maximum and minimum temperatures were the available climatological data.

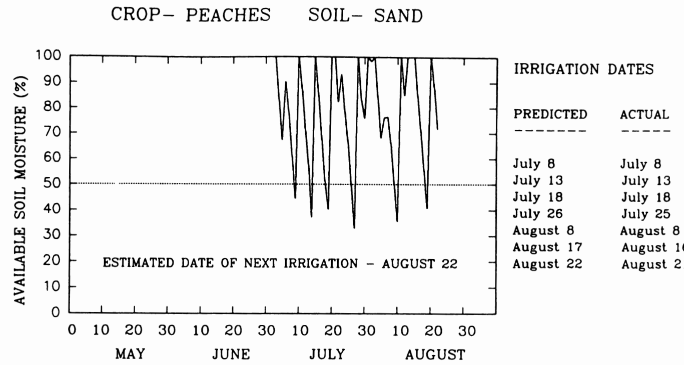


Fig. 3. Predicted irrigation dates for peach, 1983.

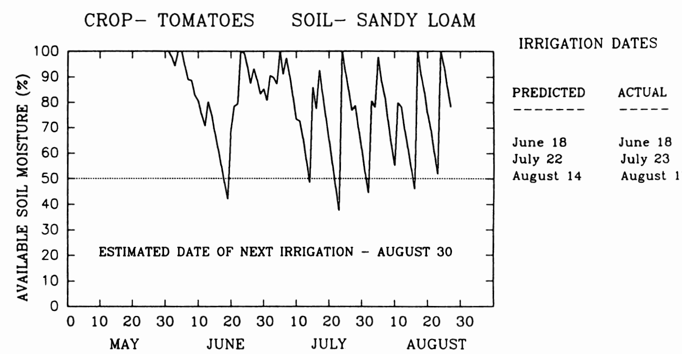


Fig. 4. Predicted irrigation dates for tomato, 1987.

The predicted irrigation dates where compared to the actual irrigation dates as determined by the expert.

Peaches were grown on a sandy soil; field capacity (top 300 mm) = 52 mm; wilting point (top 300 mm) = 19 mm. The irrigation season started the end of June and continued until the end of August. Figure 3 shows the available soil moisture level as determined by IRRIGATOR. For peach, irrigation dates predicted by IRRIGATOR closely matched the actual irrigation dates as determined by the expert.

Tomatoes were grown on a sandy loam soil; field capacity (top 300 mm) = 78 mm; wilting point (top 300 mm) = 16 mm. The tomato irrigation season started in late May and continued until the end of August. The summer of 1987 was wetter than normal and supplemental irrigation was only required three times. Figure 4 shows the available soil moisture as determined by IRRIGATOR. The irrigation dates predicted by IRRIGATOR closely matched the actual irrigation dates. Although available soil moisture levels fell below the 50% level on July 13 and July 30, IRRIGATOR did not recommend irrigation because there was a high probability of precipitation and the available soil moisture level had not fallen below the lowest allowable level.

The rule based format of IRRIGATOR is one of its strongest and most important features. Although it is possible with other methods, the use of rules provides a built in mechanism for explaining how decisions were reached and why information is needed. By displaying the facts necessary for a rule to execute and also the rules that are executed, the scheduling logic and knowledge are made readily available to the user.

This allows IRRIGATOR to be a teaching aid to novice irrigation schedulers.

IRRIGATOR is currently being revised to include new features. The current version assumes sprinkler application whereas the new version will recommend irrigation rates and amounts for drip and micro-sprinkler application of water. More detailed rules are also being added to IRRIGATOR regarding planting dates, root depths, and tree maturity for Ontario field and fruit crops. In addition, IRRIGATOR is being converted from the Personal Consultant™ Plus shell to the CLIPS (NASA 1989) environment. This will reduce distribution costs since there is no run time fee associated with CLIPS.

SUMMARY

An expert system, IRRIGATOR, has been developed to schedule irrigation in Ontario. While the majority of this data for developing the IRRIGATOR pertains to Ontario, the system can be easily adapted for use in any part of the country or the world. Unlike conventional computer programs, this expert system is not confined to looking at only one scenario. Its strength lies in its flexibility to deal with many different variables at one time. IRRIGATOR uses both equations and heuristics to predict irrigation dates and the amount of irrigation water to apply. Testing results indicate that irrigation dates predicted by IRRIGATOR match the dates determined by the expert.

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