Management Model for Sustainable On-Farm Irrigation

N. Foroud[1]

ABSTRACT

IN THE PROCESS of allocating the available water supply during an irrigation season in southern Alberta irrigation districts, irrigation farmers choose the flow rate, duration, and location for irrigation. This process makes complex demands on the delivery system, and the complexity increases as the number of crops and variability in soils increase. An irrigation management model (LRSIMM) developed at the Lethbridge Research Station can assist an irrigation farmer in establishing the desirable amount and frequency of irrigation on a farm consisting of different crops and field sizes. The model allows the timing and amount of irrigation to be modified within the constraints of the irrigation district's water supply system to meet the farmer's cultural practices and labor demands. It allows formulation of optimum water management practices for crops under variable water supplies. Results from the model can be used to develop plans for managing irrigation under deficit conditions. Such plans can help producers adapt to deficit irrigation while maintaining high yields and encouraging sustainable use of irrigation water.

INTRODUCTION

Environmental concerns and the limited availability of water for irrigation have created a need to re-examine irrigation management practices such as irrigation timing and quantities of water applied. When the available water supply is limited, water deficits are unavoidable in some periods of the irrigation season. Thus, irrigation decisions need to be based not only on the crop water requirement, but also on the crop's sensitivity to water deficits in different periods of its growth. This requires an evaluation and selection of alternative irrigation schedules that maximize yields, while conserving water, for the given water supply available. An irrigation simulation model often plays an important role in evaluation of various alternative irrigation management plans for selecting the most effective irrigation schedules.

A number of simulation models describing the soil-water-plant-atmosphere relationships for crop water requirements have been developed (Morey and Gilley 1973; Nimah and Hank 1973; Feddes et al. 1974; Rowse et al. 1983; Miyamoto 1984; Coleman et al. 1987; Camp et al. 1988; Nwabuzor 1988). The design and sophistication are a matter of individual preference. But they all include weather records, some means for budgeting soil water content, and evapotranspiration relationships. Lethbridge Research Station introduced irrigation scheduling with a computer model to the semi-arid region of the western Canadian prairies (Foroud and Hobbs 1983). It was developed to maximize the use of natural rainfall and increase irrigation efficiencies in the southern Alberta region. This paper describes an updated version of the model (Foroud et al. 1991), called the Lethbridge Research Station Irrigation Management Model (LRSIMM), along with a special analysis that utilizes long-term weather records and demonstrates crop yield response to various water deficits.

DESCRIPTION OF THE SIMULATION MODEL

A detail in model formulation and description is given by Foroud and Hobbs (1983) and Foroud et al. (1991). In order to appreciate the results of this study, a brief description of the model follows.

The model determines the daily crop water use (actual daily evapotranspiration, ET) for the field $_i$ as a function of potential daily evapotranspiration (PE), crop coefficient (KB), and the relative moisture factor (KA) by

$$ET_{i,j} = KB_{i,j} \cdot KAj \cdot PE_j + E_{i,j} \quad (1)$$

where the subscript j is the julian day number (the sequential day number of a year) and $E_{i,j}$ is additional evaporation directly from the soil surface as a result of rain or irrigation. The terms ET, PE, and E are in millimeters (mm).

A time dependent crop coefficient ($KB_{i,t}$) derived by Hobbs and Krogman (1983) for each crop is used.

[1]Agriculture and Agri-Food Canada, Lethbridge Research Centre, P.O. Box 3000, Main Lethbridge, Alberta, Canada T1J 4B1.

$$KB_{i,t} = c_1 + c_2 t + c_3 t^2 + c_4 t^3 \qquad (2)$$

$$\text{Subject to} \qquad LK \leq KB \leq UK$$

where t is time in day (the julian day number), and c_1 to c_4 are polynomial coefficients for each particular crop. LK and UK represent the lower and upper limits of the crop coefficient. An empirical equation is used to adjusted parameter t for variations in seeding date, which permits wide fluctuation in seeding date to be realistically related to an inflexible crop coefficient curve. The value of KA, sometimes referred to as a dryness factor or soil moisture stress factor, is derived by an expression relating KA to the logarithm of the percentage of available water. The potential daily evapotranspiration (PE) is derived by the modified Jensen-Haise equation which incorporates a wind parameter (Foroud et al. 1989).

A daily soil water balance procedure provides estimates of soil water ($SW_{i,j}$) in the crop root zone of a field i, taking into account ET, rainfall (R), irrigation (I), and loss of excess water (EX) to deep percolation and/or runoff. The accumulated water depletion ($D_{i,j}$) at the end of a day, j, is eventually derived. As long as water in the root zone is available to the crop ($AW_{i,j}$), it is removed from the soil to meet the daily evapotranspiration demand. Irrigation water is needed when the depletion reaches an allowable level, AD_i. This is calculated by

$$AD_i = F_i \, . \, AWC_i \qquad (3)$$

where F_i is the fraction of available water depleted before irrigation occurrence, and AWC_i is available water capacity of the field (Field capacity less wilting point). The irrigation amount (I_i) needed to replenish the depletion, including the quantity for a leaching requirement (LR_i), if necessary, and the projected irrigation date (ID_i) based on projected evapotranspiration ($PET_{i,j}$) are calculated. $PET_{i,j}$ is derived by a method described by Foroud (1990).

The computer software for the simulation model is in Fortran-77 and in Basic for an IBM-PC or compatible microcomputer. The model consists of one main and 10 subprograms [Fig. 1]. Each of the subprograms performs its own function as an independent unit, but the output of one is used as input to another during the execution of the program model. At the start of the growing season, data files consisting of pertinent information on the crop, soil water factors, weather factors, and field identification are made. The user chooses to create the data files either through an interactive mode, or before running the program. The interactive mode prompts the user for entering specific data accompanied with an example describing the data and the associated unit. The unformatted data entered by the user are identified, formatted, and stored in one of four separate data files (area file, crop file, climate file, and storage file) by the GAR, GCR, GCL and GST programs of the model [(Fig. 1)]. Program CALENDAR converts the entered date to a day number of a year (Julian day), if it is entered from the Gregorian calendar, and vice versa.

After initialization, only weather data are required. These are current date, maximum and minimum temperatures, solar radiation, wind run, rainfall, and irrigation. The climate file must be updated by the user with new weather data each time the model is run. The area and crop files remain unchanged once they are created, and the storage files are automatically updated by the model each time it is run. The model should be run weekly, but it can be run any day within the week, if significant rainfall occurs.

The model has been also programmed in Basic for IBM-PC compatible microcomputers. This version, unlike the Fortran version, includes a built-in crop coefficient (polynomial constants) for 14 important crops in the region. The model operates in a menu-driven mode, in which the user navigates through the different parts of the program by selecting options from the menu, using arrows and enter keys.

In both Fortran and Basic versions, operations are accomplished using prompt commands so that the user is not required to type any specific computer commands. The Basic version of the model produces the same outputs as the Fortran version when using the same input data. The Fortran version of the model can be adopted to other regions. Some relatively minor changes and validation of the model should be required. The model allows the user to input locally derived values of polynomial constants of crop coefficients and coefficients required for potential evapotranspiration. Furthermore, the PE program [(Fig. 1)] can be replaced to allow the calculation of daily potential evapotranspiration by any other method appropriate to the region.

The accuracy of the model was tested and verified with many field data collected from several areas. For more details on model description and verification see Foroud et al. (1991).

IRRIGATION MANAGEMENT STRATEGIES AND WATER CONSERVATION

In LRSIMM, a management approach that uses depletion level was implemented to determine the time of the next irrigation. In this approach, the numerical value of coefficient F_i in equation 3 is selected according to the crop and soil type, crop stress (deficit irrigation), and the assumption that the soil water content is not to be allowed to drop below the allowable depletion level. Numerous irrigation management strategies can be examined by the model, and the effects on soil water of an irrigation at any target depletion level for small, relatively moderate, and large plant water stress, as well as those of the irrigation actually applied by the farmer can be evaluated. For example, in several field tests conducted, variations were found in the amount of irrigation water applied and the timing of application. As a result, the extent of depletion varied widely anywhere from 20 percent to 90 percent. In some fields, particularly those irrigated by the gravity surface irrigation method, depletions exceeded the farmers' target depletions. Irrigation timing is a major management decision. Most irrigation farmers schedule their irrigation at fixed intervals, usually 3 or 5 weeks apart. The possible problem in this approach is that the soil water may reach levels that cause yield reduction. Shorter fixed intervals, as used in center-pivot systems, may be advantageous, provided that the proper amount of irrigation needed by the crop can be applied in time to avoid excess water.

[Figure 2] illustrates the irrigation management strategies used in four commercial fields of wheat, each from a different farm. The first two fields a and b are under gravity surface irrigation and the other two under sprinkler irrigation systems; wheel move in field c and center pivot in field d. There was one irrigation occurrence in field a. A large amount of irrigation water was applied (220 mm) in this early irrigation event (7 June). About one third of this amount could have been applied at that time in order to bring the soil moisture to the field capacity (FC) level. By 10 July, more than 50 percent of the available soil water was depleted, leaving the crop under high moisture stress afterward. From 20 July onward, the soil water content was essentially at wilting point. As a result, the crop was under excessive water stress from early July until the end of the growing season. Further, a considerable portion of the water from this early irrigation was obviously lost through runoff and deep percolation, increasing the danger of waterlogging, salinization, and contamination of surface and ground water resources. Scheduling the most efficient timing and amount of irrigation for a sustainable use of this irrigation water could be achieved using LRSIMM, for example by irrigation at 60 percent depletion of AWC.

In contrast, irrigation management strategies in field b were different but not better. The field was not irrigated until 17 July, when almost 90 percent of the AWC was depleted, causing excessive plant water stress during the period in which the irrigation was delayed. The dotted line in [Figure 2] (a and b) represents the simulated soil moisture when irrigation was scheduled at 70 percent depletion of AWC.

Relatively better irrigation management strategies can be seen in fields c and d under sprinkler irrigation system. There were two irrigation occurrences in field c under wheel move, each a few days earlier than that predicted by the model at 55 percent depletion of AWC. The field was under-irrigated in the second event. In contrast, field d under center pivot, received five irrigations (frequent irrigation strategy) that applied a total of 230 mm of water to maintain soil water at or above 40 percent AWC during the irrigation season. Considerable energy and water losses as a result of this frequent irrigation strategy could have been saved, while achieving the same goal, by selecting an effective management strategy by LRSIMM. Irrigation water losses represent excess pumpage and, hence, excess energy expended. The model, as seen in [Figure 2 (d)], shows that soil moisture could even be kept at or above 30 percent AWC with only three irrigation occurrences, 60 mm each time or a total of 180 mm per season.

[Figures 3] to 5 show the results from an analysis of irrigation management strategies performed with LRSIMM. The analysis incorporates long-term climatic data (14 years) and information from published data on crop growth and yield for potato (Lynch et al. 1988) and for soybean (Foroud et al. 1993). These data were used to develop a crop yield response with moisture stress for potato and for soybean, [Figure 3 (a and b)]. The model was used to determine the relationship between crop water use (ET) and moisture stress (L), [Figure 4], and the relationship of crop relative yield and crop relative water use [Figure 5]. These results show that irrigation schedules have a major effect on crop water use (ET). Adequate irrigation during the crop season can increase ET and, hence, crop yield, but detailed economic analysis for optimum irrigation (not shown in this paper) may depend on the price of water, the value of the crop, and the cost of irrigation. In conclusion, as a tool for comparing different irrigation management alternatives, LRSIMM can help attain more effective water use, and reduce irrigation water losses and their adverse impact on environmental quality while maintaining optimum crop yields.

SUMMARY AND CONCLUSION

A new method of irrigation management is needed for economic and environmental reasons. LRSIMM simulates daily crop water use and the timing and amounts of irrigation at specific soil moisture levels, using climatic, crop, and soil data. The model calculates evapotranspiration based on the assumption that water use is proportional to climatic demand, and that the climatic demand can be estimated using an appropriate equation for potential evapotranspiration. The reliability of the model in estimating soil water is controlled by the assumptions used for describing field conditions as well as by the quality of input data.

Crop yield models were used to predict crop yield for irrigation at different stress levels for 14 years of climatic data. Relationships that describe yield response with moisture stress for potato and for soybean crops were developed between crop water use (ET) and moisture stress (L), and between crop relative yield and crop relative water use. Results from the model were used to demonstrate that producers could benefit from examining the effect of various irrigation strategies, including deficit irrigation, as they plan their long-term irrigation management strategy.

References

Camp, C.R.; Christenbury, G.D.; and Doty, C.W. 1988. Scheduling irrigation for corn and soybeans in the southern coastal plains. Trans. ASAE 31:513-518.

Coleman, P.H.; McClendon, R.W.; and Hook, J.E. 1987. Computer analysis of soybean irrigation management strategies. Trans. ASAE 30:417-423.

Feddes, R.A.; Bresler, E.; and Neuman, S.P. 1974. Field test of a modified numerical model for water uptake by root systems. Water Resour. Res. 10:1199-1206.

Foroud, N.; and Hobbs, E.H. 1983. The LETHIRR Irrigation Scheduling Model: Description and operation procedures. LRS Mimeo Report 5:1-31. Lethbridge, Alberta, Canada: Agriculture Canada.

Foroud, N.; Chang, C.; and Entz, T. 1989. Potential evapotranspiration in the southern Alberta Chinook region. Can. Water Resour. Jour. 14:30-42.

Foroud, N. 1990. Computer simulation model for irrigation system operation. *In* Proceedings of IRDC-90: Irrigation research and development in the 1990s. University of Lethbridge, 169-174.

Hobbs, E.H.; and Krogman, K.K. 1983. Scheduling irrigation to meet crop demand. Contribution 1983-10E:1-10. Agriculture Canada, Research Branch, Ottawa, Ontario, Canada.

Miyamoto, S. 1984. A model for scheduling pecan irrigation with microcomputers. Trans. ASAE 27:456-463.

Morey, R.V.; and Gilley, J.R. 1973. A simulation model for evaluating irrigation management practices. Trans. ASAE 16:979-983.

Nimah, M.N.; and Hanks, R.J. 1973. Model for estimating soil water, plant, and atmospheric interrelations: Description and sensitivity. [Soil Sci. Soc. Am.] 37:522-527.

Nwabuzor, S.S. 1988. Field validation of an empirical soil water model. [Agric. Water Manage.] 14:317-327.

Rowse, H.R.; Mason, W.K.; and Taylor, H.M. 1983. A microcomputer simulation model of soil water extraction by soybeans. Soil Sci. 136:218-225.

Figure 1. General flow chart of the Lethbridge Research Station Irrigation Management Model (LRSIMM). Flow is from top to bottom and left to right. Each box refers to one computer program. GAR, GCL, GCR, and GST create and process the area file, climate file, crop file, and storage file, respectively. PE, ET, and IR, respectively, calculate potential evapotranspiration, actual evapotranspiration, and irrigation requirements. Print provides various output files.

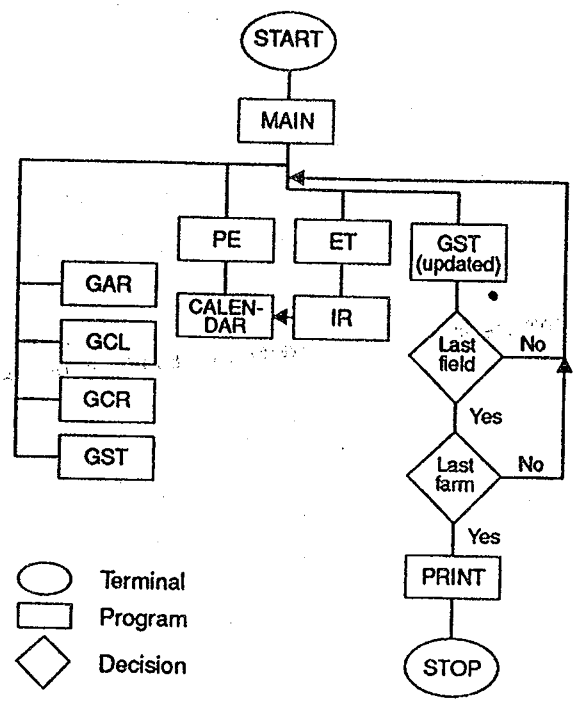

Figure 2. Soil water contents in 4 spring wheat fields based on hypothetical irrigations initiated at 30 percent depletion of AWC (for a center pivot sprinkler), 55 percent (for a wheel move sprinkler), and 70 percent (for a gravity surface irrigation method), and as actually applied by farmers. Solid and dotted bars represent rainfall and irrigation, respectively. Numbers above the dotted bars are irrigation amounts in mm. AWC = FC-WP.

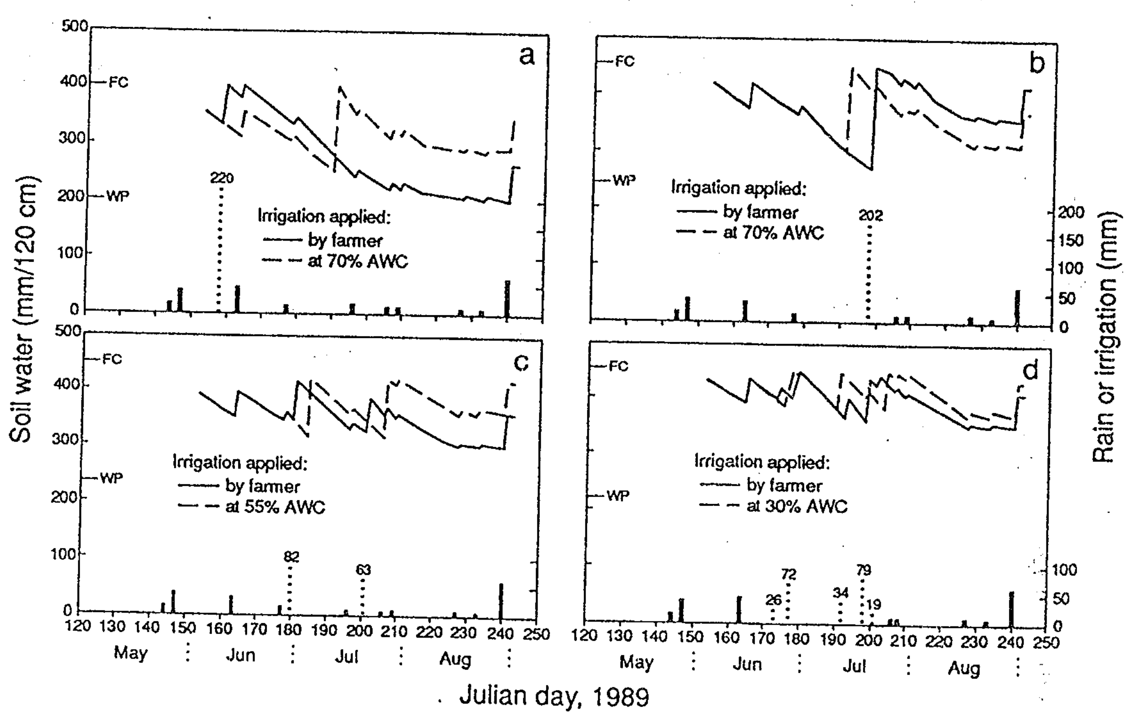

Figure 3. Effect of soil moisture stress on crop water use (ET) from 14 years (1978-1991) 0f model analysis.

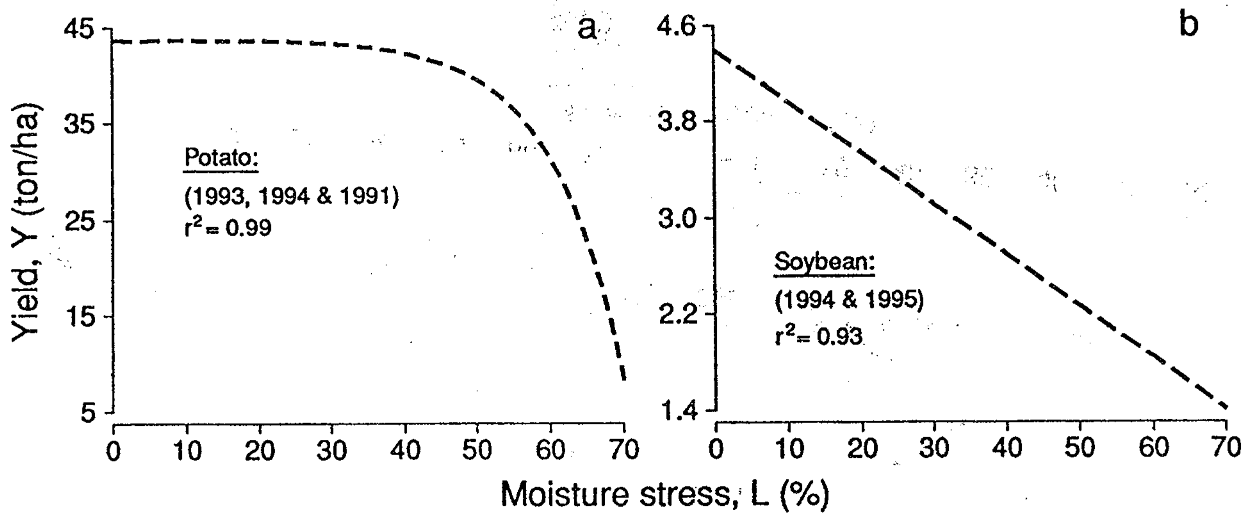

Figure 4. Effect of soil moisture stress on two crop yields; (a) potato crop and (b) soybean crop.

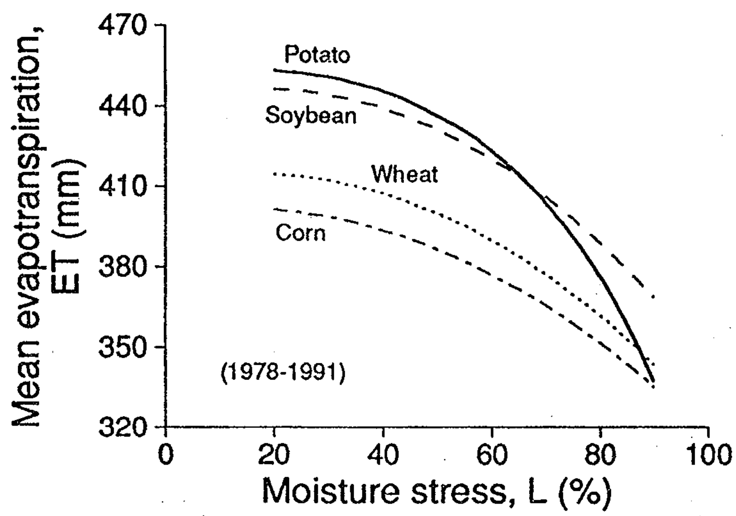

Figure 5. Relationship between relative yield and relative water use from long-term model analysis (1978-1991).]