Show Me Irrigator, Missouri's Irrigation Scheduling Program

ABSTRACT

A new irrigation scheduling program in spreadsheet format was developed by the University of Missouri and funded by the Missouri Department of Natural Resources. The software, tentatively called ***Show Me Irrigator***, incorporates unique features, such as rainfall run-off estimator, yield prediction, and automatic generation of irrigation aids for local media.

INTRODUCTION

Irrigation scheduling using climatic weather data involves many calculations and thus is ideal for computers. However, there are relatively few computer programs available today. This project was undertaken to develop spreadsheet software that would (a) incorporate the recommended procedures of FAO-56, (b) utilize a run-off module, (c) predict crop yield, and (d) generate graphical irrigation aids for newspapers.

The actual percentage of farms using scientific irrigation scheduling methods (either soil moisture monitoring or computer scheduling) on a national basis is only 9.6 and 2.3%, respectively (Table 1). In some cases, the reason that scheduling is not done is that, like in much of the southwest, water resources are so limited that scheduling becomes a mute point as pumps are kept on continuously as the farmer tries to play " catch up". Depending on rooting depth, soil type and expected rainfall, unless a water resource of about 3.0 to 4.0 gallons per minute per irrigated acre exists, the water supply is marginal for full irrigation, and scheduling would likely remain a mute point. However, for those areas that do have ample water, scheduling should be employed as it is shown to increase yields. Table 2 shows the results of four years of survey data from Missouri farmers where irrigators who used scheduling grossed about $40 per acre more than irrigators who did not schedule.

Table 1. Percentages of farms using irrigation scheduling by either soil moisture monitoring or computer program (USDC, 2001)

State	Soil Moisture Monitoring	Computer Program	State	Soil Moisture Monitoring	Computer Program
Alabama	10.6%	0.8%	Nebraska	6.0%	0.3%
Alaska	17.1%	---	Nevada	3.9%	0.2%
Arizona	8.5%	0.2%	New Hampshire	7.6%	---
Arkansas	9.6%	5.3%	New Jersey	12.7%	0.2%
California	13.7%	1.7%	New Mexico	5.7%	0.3%
Colorado	4.5%	1.5%	New York	13.7%	3.7%
Delaware	12.4%	0.4%	North Carolina	6.5%	0.2%
Florida	16.7%	0.0%	North Dakota	8.7%	3.1%
Georgia	5.3%	2.4%	Ohio	11.0%	
Hawaii	3.5%	0.5%	Oklahoma	6.6%	0.5%
Idaho	4.2%	0.2%	Oregon	5.7%	0.1%
Illinois	7.1%	0.5%	Pennsylvania	7.7%	0.6%
Indiana	8.4%	0.4%	Rhode Island	21.4%	---
Iowa	10.9%	1.0%	South Carolina	9.5%	0.2%
Kansas	10.8%	0.8%	South Dakota	16.3%	0.3%
Kentucky	5.2%	1.7%	Tennessee	4.7%	2.2%
Louisiana	3.4%	0.4%	Texas	9.2%	1.5%
Maine	16.6%	---	Utah	3.3%	0.1%
Maryland	11.9%	0.2%	Vermont	10.9%	---
Massachusetts	20.8%	2.3%	Virginia	7.7%	0.5%
Michigan	11.0%	2.7%	Washington	7.9%	0.8%
Minnesota	14.0%	0.5%	West Virginia	4.0%	---
Mississippi	6.7%	1.4%	Wisconsin	10.6%	1.7%
Missouri	**5.5%**	**1.9%**	Wyoming	2.6%	0.1%
Montana	4.3%	1.8%	**USA**	**9.6%**	**2.3%**

Table 2. Comparison of yields and difference in gross returns for irrigators who scheduled versus those that did not schedule irrigation, SE Missouri, 2000-20003. Sample size in parenthesis (after Henggeler, 2003).			
Crop	**Irrigators Who Scheduled** (bu. [or lbs.] /acre)	**Irrigators Who Did NOT Schedule** (bu. [or lbs.] /acre)	**Gross Return from Scheduling** ($/acre)
Corn	179.5 (49)	168.7 (153)	$26.90
Cotton	954.6 (14)	871.1 (82)	$54.28
Soybeans	45.6 (22)	42.3 (193)	$18.98

SPECIAL FEATURES

The program developed, called ***Show Me Irrigator***, has many features, some of them innovative and not in other irrigation scheduling programs. The program uses EXCEL spreadsheet with Visual Basic macros.

The science behind the scheduling is based on FAO-56 (Allen, et al., 1998). It uses both real-time and historic weather. Reference evapotranspiration (ET_o) is calculated using FAO-56 and the dual crop coefficient (K_{cb}) method, which calculates soil evaporation and crop transpiration separately. When real-time weather is not input, historic data is automatically inserted. Historic weather files exist for 5 locations in Missouri. There is also the option to generate a historic weather file for other locales by inputting monthly mean values of maximum and minimum temperature, wind speed, and minimum relative humidity. This monthly data is used to generate the historic file that includes daily values for the items mentioned above, plus estimated daily $ET_{o,}$ and daily values for two types of Heat Units (HU) (a corn HU [86ºF maximum and 50ºF base] and regular HU [60ºF base]). The estimated daily ET_o for the historic weather file is based on the Blaney-Criddle calculation method. The Blaney-Criddle values are modified to approximate Penman-Monteith values for Missouri conditions using Equation 1:

$$ET_{o\_PM'} = 0.85\ ET_{o\_BC} - 0.03 \qquad \text{(Eq. 1)}$$

where,

$ET_{o\_PM'}$ = estimated Penman-Monteith ET_o [in]
ET_{o_BC} = Blaney-Criddle ET_o [in]

Future versions of ***Show Me Irrigator*** will use the Hargreaves-Samani calculation method with a correction factor to estimate the Penman-Monteith ET_o values used in the historic weather files. Current investigations indicate this provides a better estimate than the Blaney-Criddle method currently used.

An image of the main worksheet is shown in Figure 1. Some of the features of the program are described below.

Crop Coefficient Curves

The program currently supports corn, soybeans and cotton. The crop coefficient curves (K_c for the single coefficient method [effects of soil evaporation and crop transpiration lumped together] and K_{cb}) were developed specifically for Missouri weather conditions. However, tools to modify the K_c and K_{cb}[1] curves are part of the program.

End-of-season calculations

In most existing irrigation scheduling programs end-of-season water use estimates are very poor. One of the main reasons for this is that, while the beginning of the season (either planting or emergence) is obvious, when the end of the season occurs is less clear. However, having a clear estimate of when a crop will begin to senesce and die is important for two reasons. First, irrigation scheduling programs that call for irrigation water after a crop has terminated will decrease farmers' overall credibility in irrigation scheduling. Second, termination of irrigation too early in the season may be hurting corn and soybean yields in the mid-West (Henggeler, 2004).

[1] Since the program normally uses the dual coefficient method (K_{cb}), the term K_{cb} is used in this paper, but implies both K_{cb} and K_c.

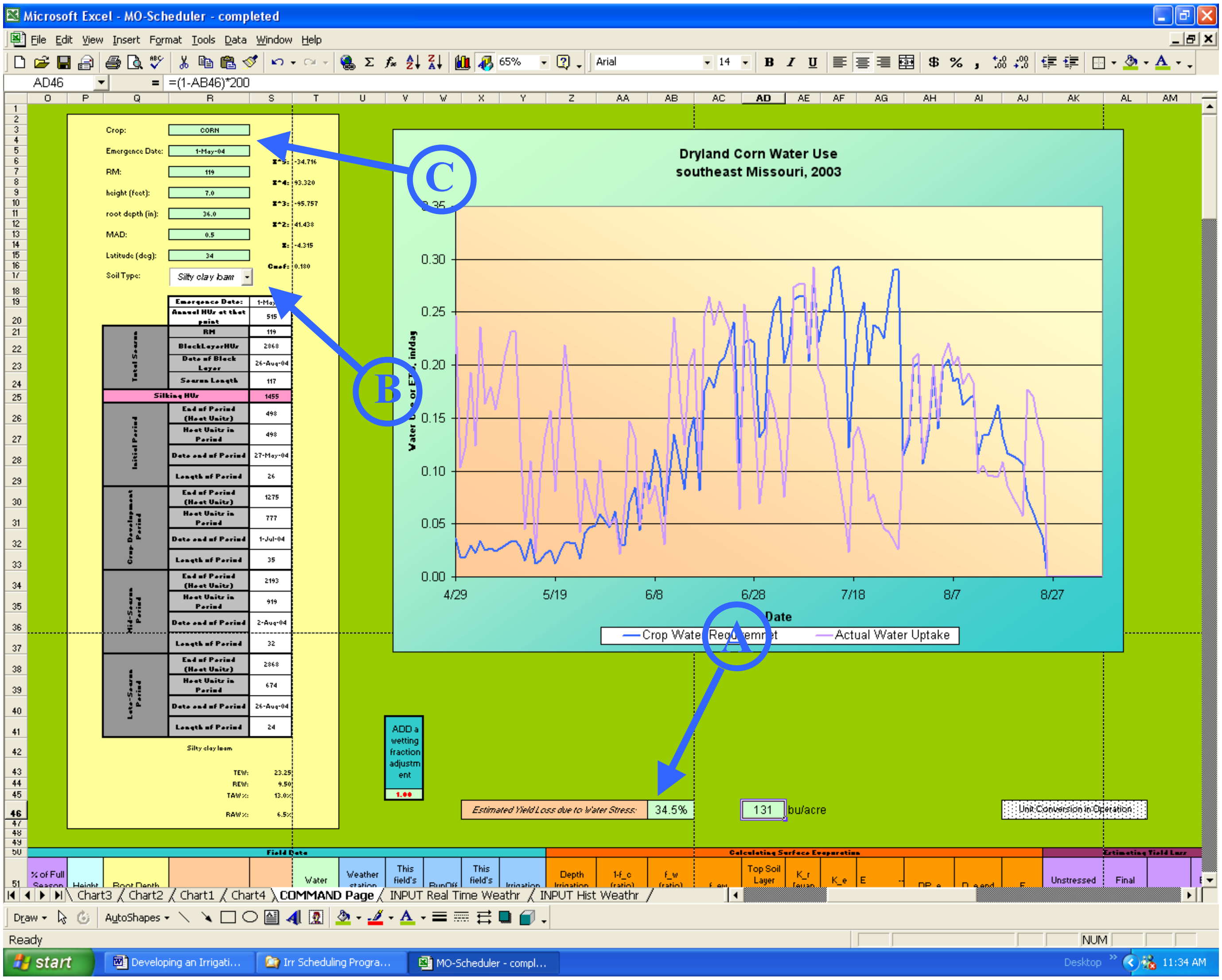


Fig. 1. Main worksheet for *MO-Scheduler*. Item "A" is a yield projector based on crop moisture stressed incurred, item "B" is a pull-down menu with all major soil types, and item "C" is location for input ting data. Providing emergence date and RM is enough to provide breakdown of dates and HUs to major physiological events.

CORN. The termination date of *corn* can readily be predicted. The corn HU growth model (86◦F / 50◦F) that is universally used was developed at Texas A&M University in the 1950s (Gilmore and Rogers, 1958). Seed companies have made use of it for many years to predict both *silking* (very important for breeders) and *black layer* (important in quantifying the growing period required) in their hybrids, so its accuracy has been well established. However, seed companies use another scale to actually categorize hybrid season length, Relative Maturity (RM). RM is the estimated length in days of a hybrid's season. Farmers in a location may commonly have a 10-day span in the hybrids they are using. For example, in southeast Missouri (SEMO) the normal range in hybrids is RM 109 to RM 119. This in itself represents about a 10% error for irrigation programs that deal with corn generically. On top of this, RM values are only approximations based on "average" planting dates for that region, outside of this planting window and local weather patterns, the RM values loose accuracy. For example, in SEMO a hybrid with a RM value of 113 could have a season length ranging from 76 to 124 days depending if it emerged 1 Apr or 1 Jun.

Seed companies normally provide data on HUs to black layer (HU_{bl}). In cases where it is not known, the RM value can be used to predict HU_{bl} as seen in Equation 2.

$$HU_{bl} = -(0.0063 \times RM^3) + (2.20742 \times RM^2) - (204.17 \times RM) + 8407.5 \qquad \text{(Eq. 2)}$$

where

HU_{bl} = ∑ HUs (86ºF limit on max. temperature and 50ºF-base) to black layer [ºF]
RM = seed company rating system for hybrid season length [days]

The data to create Eq 2 came from many hybrids from three of the major corn seed companies (Pioneer, DeKalb and Micogen). Figure 2 shows a graph of Relative Maturity values versus HUs to reach black layer and silking.

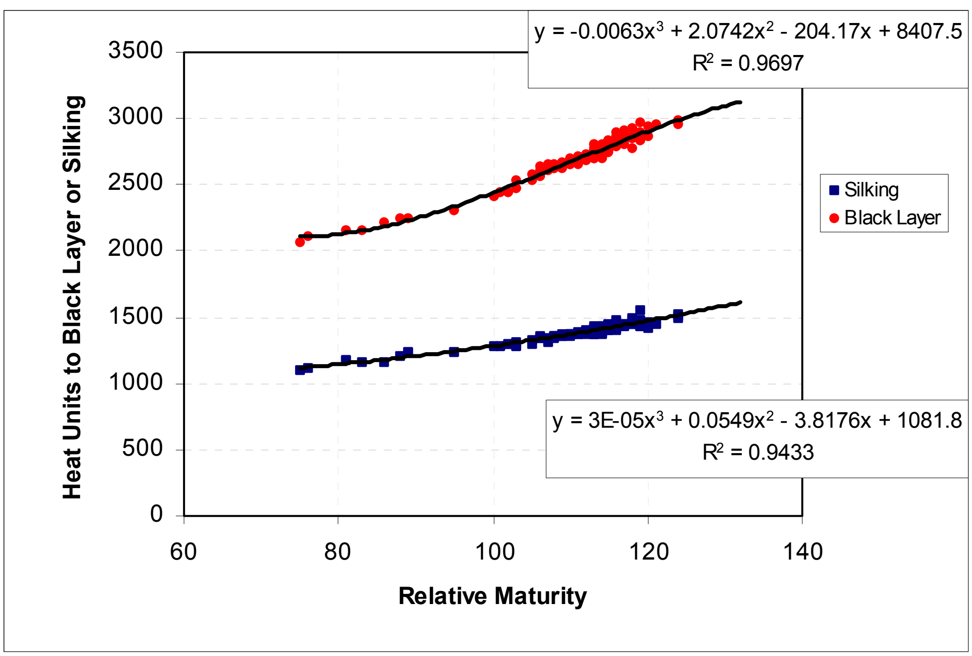


Figure 2- Heat Units to reach silking and black layer for various Relative Maturity ratings of corn.

SOYBEAN. The termination date of soybean is more difficult to determine since most soybeans are day-length sensitive. Based on their normal growing period soybean varieties are categorized by Maturity Groups (MG). The smaller the MG value, the shorter the season. Farmers in Missouri plant varieties with MG values ranging from III to VII. An equation was developed to predict the expected season length of a soybean variety based on its MG, date of planting, and latitude. Data for this model (Eq. 3) was gathered from reported variety tests conducted throughout the Midwest and mid-South that utilized varieties with varying MG values and which reported soybean termination dates for the varieties in the trial.

$$L = -(0.71 \times DOY) + (0.0015 \times DOY^2) + (0.92 \times Lat) + (9.1 \times MG) + 127.6 \qquad \text{(Eq. 3)}$$

where

L = the season length [days]
DOY = numerical day of year of planting
Lat = latitude of location [ºF]
MG = Maturity Group of soybean variety

The computer program uses Eqs. 2 and 3 plus the emergence date to determine when, respectively, the corn and soybean will terminate. Thus a reasonable time framework is laid out on which to building the crop coefficient curve.

Coefficient Values

The FAO-56 method (Allen et al., 1998) was used to modify the crop coefficient values and curves. The FAO method takes a minimalist approach, breaking the growing season up into only four periods: Initial (prior to planting to 10% of canopy coverage), crop development (from 10% through about 70-80% coverage [corresponding to a Leaf Area Index of 3.0]), mid-season (70-80% cover until start of maturity when leaves begin to show aging), and late season (maturity to full senescence or crop harvest). FAO-56 provided information on *length in days* for the four periods plus total season length, planting date, plant height, and region of reference for a number of crops, including corn and soybeans. Analyzing the presented data from around the world (6 corn and 4 soybean studies) indicated that the relative length for each physiological period was actually a better method to separate the four periods than number of days. Table 3 shows the relative season length for corn and soybeans for each growth period.

Table 3. Average relative length of each of the four growth periods for corn and soybean

CROP	Initial Period	Crop Development Period	Mid-season Period	Late-season Period
Corn	.174	.271	.320	.235
Soybean	.150	.204	.461	.185

In breaking the season into the 4 parts, just three K_{cb} values (initial, mid-season, and end) are used to describe the entire season. They are referred to as K_{cb_ini}, $K_{cb\_ mid}$, and K_{cb_end}, respectively. Suggested values for these 3 points are provided in FAO-56. However, the placement of these 3 points in the horizontal direction is based on time (or relative season length in our case) of the 4 growth periods. Additionally, the values of $K_{cb\_ mid}$, and K_{cb_end} are based on locales with an average daily minimum Relative Humidity value of 45% and an average daily wind speed of 2 m/s. A procedure is presented in FAO-56 to allow for adjustment. The minimum RH values in SEMO for the periods in question was slightly higher (53%-60%) then the standard RH value and the wind speeds were slightly less (1.12 to 1.45 m/s) and so $K_{cb\_ mid}$, and K_{cb_end} were adjusted accordingly. This coefficient-adjustment tool is a module in the program.

In order to facilitate flexibility, the x-axis value for the crop coefficient curves used in the computer program was based on percentage of the seasonal HUs. Although soybean flower initiation and other factors are not HU-related, early season canopy growth is. The HUs for the time period from emergence to crop termination (determined by either Eq 2 or Eq 3) was calculated based on historical weather data for each site. The final corn and soybean crop coefficient curves, along with the reconstructed FAO-56 minimal curve, are seen in Figs. 3 and 4.

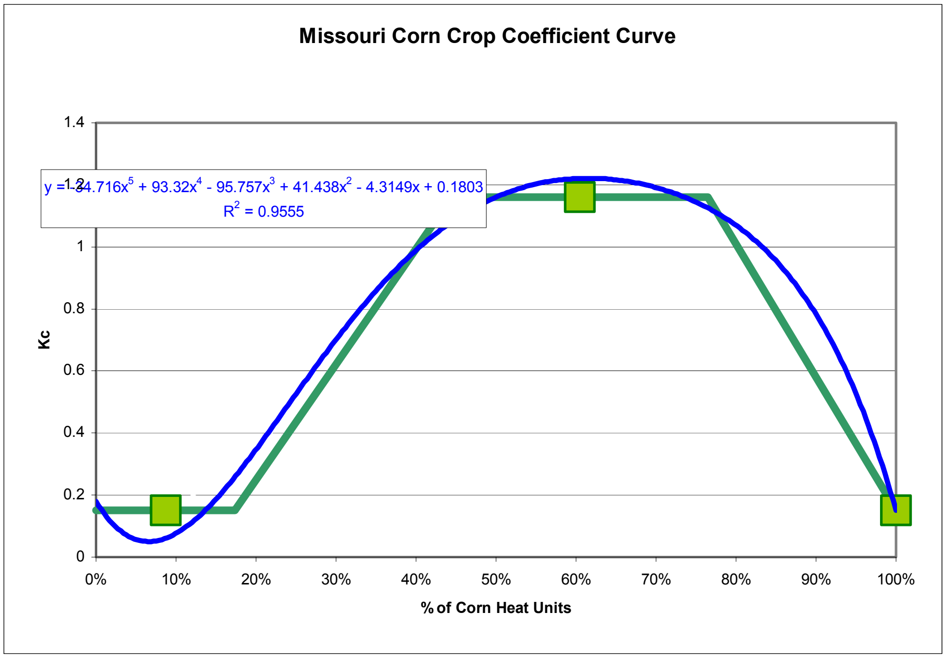


Figure 3- Basal crop coefficient curve for corn in Missouri with a baseline of % of seasonal Heat Units. The FAO-56 4-section curve is shown also.

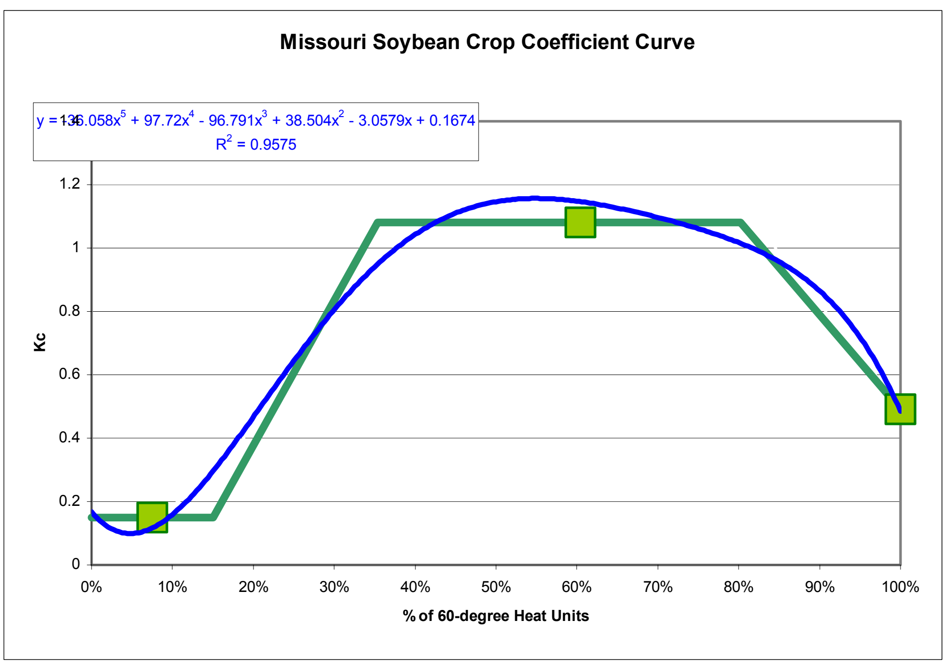


Figure 4- Basal crop coefficient curve for soybean in Missouri with a baseline of % of seasonal Heat Units. The FAO-56 4-section curve is shown also.

Yield Estimates

The program is able to estimate yield based on water stress during the season. The procedure used is based on FAO Irrigation and Drainage Paper No. 33, Yield Response to Water (Doorenbos and Kassam, 1979). One of the main purposes for developing this tool is to help growers who do not have adequate water to fully irrigate all their crops. This is often an occurrence in SEMO where an early-planted corn crop is finishing off about the time late season soybeans begin to need water.

The current estimator is based on season-wide water short falls. FAO-33 actually has more intense methods that allow estimates to be based on the growth stage when the moisture stress occurred. In future releases of the software this procedure will be added.

It is very simple to use the program to develop "what if" scenarios. For example, Fig. 5 shows how relative yield for different emergence dates is affected by rainfall patterns 55 days later. It just took a few moments to gather the data.

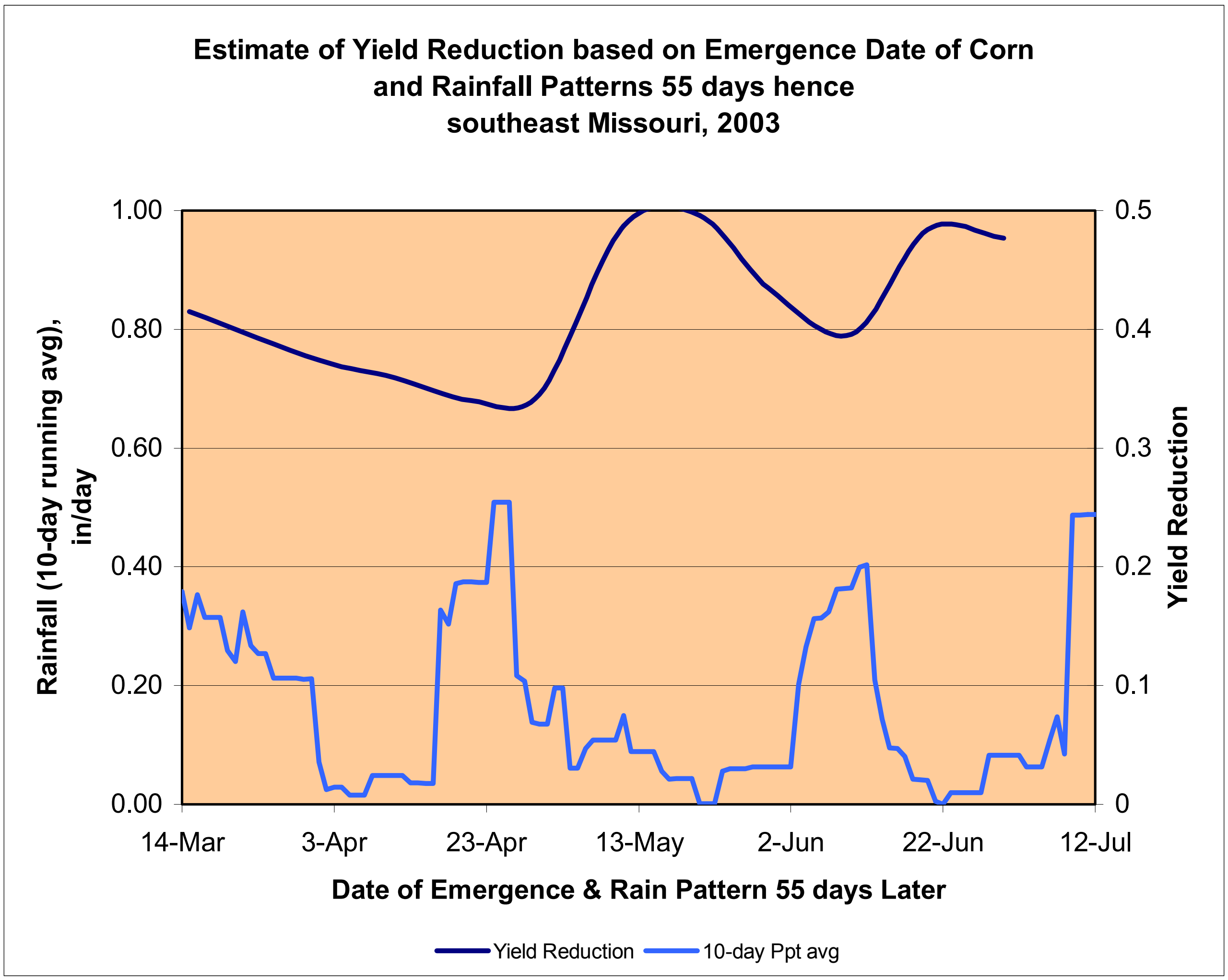
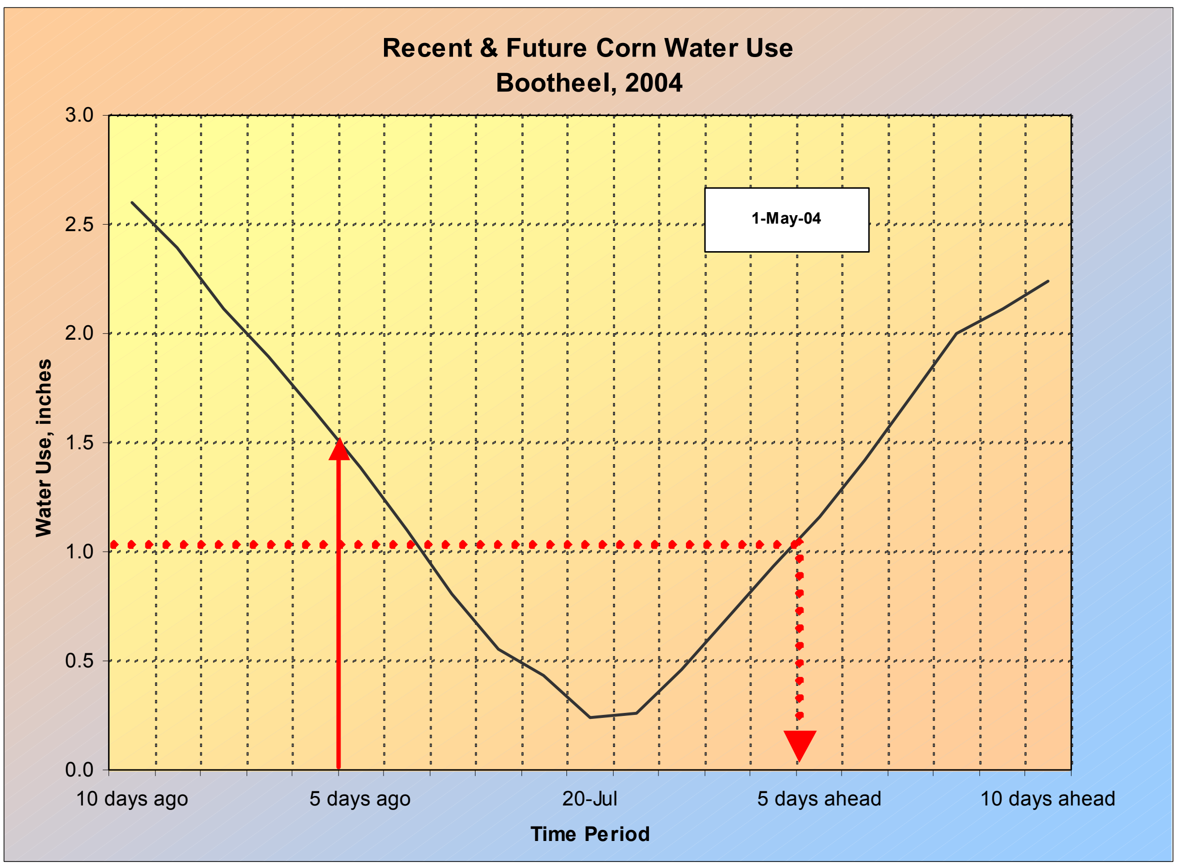


Figure 5- Changes in relative yield reduction based on emergence date overlaid with rainfall patterns (10-day running average) 55 days later. The information was generated with MO-Scheduler.

Generating of Irrigation Scheduling Aids
Current estimates are that only about 15% of Missouri irrigators schedule. Farmers, who are not currently scheduling, could benefit from timely water use updates that might be published in local papers. The program was set up to automatically create irrigation aids like the one in the text box below.

It is very important to use K_c, not the K_{cb}, values to generate public release information since the correct data on rain and past irrigations is not known!

EXAMPLE: This is an automatically generated irrigation aid meant for release to newspapers. It works like this: a farmer wishes to irrigate when 2.5 inches of water of soil moisture storage is used up. He knows that he watered 5 days ago. From that date until now (assuming this is Jul 20), he used up 1.5 inches of water. He needs to use up only 1.0 more inch of water (2.5 – 1.5) before he irrigates again. He goes over to the left axis and moves out at the 1.0-inch mark until he hits the graph line. Then he goes downward to see that we will need to water in 5 days, or Jul 25.



Another educational tool that the program can generate automatically is a tabular representation of water use information. A mock up is shown as Figure 7. We have already contacted newspapers in the irrigated areas of the state concerning the best methods (PDF, spreadsheet, etc.) for getting this information to them.

Water Use Report

(May 9th, 2004)

Sponsored by the University of Missouri and the Missouri Department of Natural Resources

Period		Max Temp (degrees F)	Min Temp (degrees F)	ETo (in/day)	CORN				
					Date of Emergence				
					20-Mar	31-Mar	11-Apr	30-Apr	11-May
					Water Use, inches/day				
Days Ago	10	76.8	52.1	0.21	0.03	0.02	0.01	0.04	0.04
	9	76.5	60.6	0.16	0.03	0.02	0.01	0.03	0.03
	8	77.9	60.9	0.12	0.02	0.01	0.01	0.02	0.02
	7	70.2	49.8	0.11	0.02	0.01	0.01	0.02	0.02
	6	67.3	47.8	0.15	0.03	0.02	0.01	0.02	0.03
	5	62.0	44.7	0.12	0.03	0.02	0.01	0.02	0.02
	4	72.8	47.8	0.19	0.05	0.03	0.02	0.02	0.03
	3	85.5	58.2	0.24	0.06	0.04	0.03	0.02	0.04
	2	86.4	60.9	0.25	0.07	0.04	0.03	0.02	0.05
	1	78.0	56.3	0.15	0.05	0.03	0.02	0.01	0.03
05/09/04		78.3	56.6	0.15	0.05	0.03	0.02	0.01	0.03
Days Ahead	1	78.6	56.9	0.15	0.05	0.03	0.03	0.01	0.03
	2	78.9	57.2	0.15	0.06	0.04	0.03	0.01	0.03
	3	79.2	57.5	0.15	0.06	0.04	0.03	0.01	0.02
	4	79.4	57.8	0.15	0.07	0.05	0.04	0.01	0.02
	5	79.7	58.1	0.15	0.07	0.05	0.04	0.01	0.02
	6	80.3	58.7	0.15	0.07	0.05	0.04	0.01	0.01
	7	80.6	59.0	0.16	0.08	0.06	0.05	0.01	0.01
	8	80.8	59.3	0.16	0.08	0.06	0.05	0.01	0.01
	9	81.1	59.6	0.16	0.09	0.07	0.06	0.01	0.01
	10	81.3	59.8	0.16	0.09	0.07	0.06	0.02	0.01

Team Up!

Figure 6- A tabular representation of local water use data that will be sent to local papers.

Run-off Module

An irrigation scheduling program is only as good as the data being used in the program. While the irrigation community has devoted much effort into determining the most appropriate ET equation, little has been done in recent years in determining run-off from rain, other then a Nebraska University fact sheet (Cahoon et al., 1992). This fact sheet was based on the SCS Runoff Equations numbers developed in the 1950s. Review of the literature shows that this methodology is employed worldwide in determining information on storm events, river flow, etc. Even very complex hydrology models rely on this procedure, which is based on the classification of soils into four run-off categories: A, B, C, and D. Almost all soils in the USA have been so classified. Other main factors include category of crop (e.g., row, pasture, etc.), tillage system, and gross rainfall amount and antecedent moisture conditions. These data are used to generate "CN" values and CN-curves. The solution was traditionally solved graphically.

A module in the program estimates run-off from a rain. The original concept was to have the calculation procedures internally within the program. However, since this entailed that each day of the year in the weather file would need this relatively complicated equation, a compromise solution was to have a single calculator on one of the worksheets within the ***Show Me Irrigator***. In the event of rain, the user can quickly input the information need to determine how much was run-off and how much was effective. Figure 7 shows the screen image of the run-off calculator.

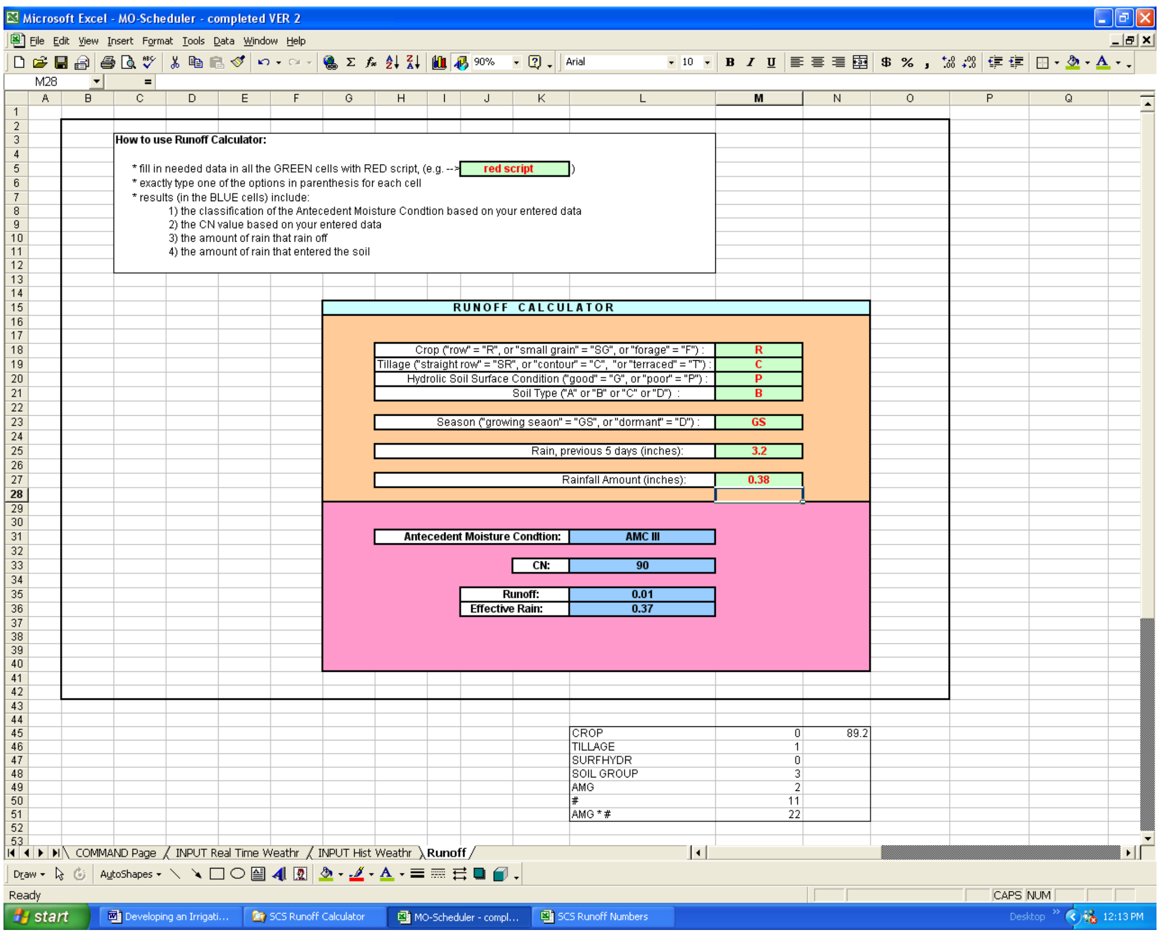


Figure 7- The screen image of the SCS Runoff calculator.

FUTURE WORK

Other features will be hopefully be added to ***Show Me Irrigator*** in future modifications. These include:

- Deep Percolation. Deep percolation is an important factor in safe water-nitrogen management. A graphical display of deep percolation will later be put into the program.

- Enhancing crop yield predictors. Future yield prediction will be based on more intense diagnostic tools that will incorporate the effect of moisture stress based on the growth stage it occurred.

- Soil moisture tension. Values of volumetric moisture content will be converted to soil moisture tension in the program. Several equations for tension versus water content were developed, but were not able to be put into the current version because of time constraints.

- Calculation of the ET_o. Since other software existed to calculate FAO Penman-Monteith reference evapotranspiration values, it was not added to this program. Future version will probably include this capability.

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