Using a Programmable Calculator for Determining Potential Evapotranspiration Rates[1]

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Abstract

A program is presented allowing the computation of uncorrected potential evapotranspiration (ET_p) rates using a low-cost (<$50) hand-held programmable calculator. This program requires the user to supply average local or on-site monthly temperatures. The first part of the program computes the annual heat index and the exponent necessary for ET_p determination. The second part of the program computes monthly ET_p rates by the Thornthwaite procedure as each average monthly temperature is keyed in. Comparisons of computed ET_p rates with measured actual evapotranspiration (ET_a) rates of various container-grown nursery crops show good correlation.

Index words: irrigation, water requirements

Introduction

Supplying irrigation in correct amounts and at proper intervals can be pivotal in the successful production of a nursery crop. Water use factors have become critically apparent in many areas of the country where water shortages have forced governmental regulatory intervention that affects nursery production through water rationing or water rights denial.

To assure uninterrupted water supply for horticultural use, nursery managers sometimes need to justify crop water requirements to the various governmental agencies that regulate water rights. In some cases, nursery managers can do this by citing published work in which actual evapotranspiration (ET_a) rates for nursery crops have been documented (4, 5, 6, 8). However, most nursery crops lack sufficient data due to the diversity of crops and growing conditions. The need to make justifiable crop water use projections can be met by the use of computed potential evapotranspiration (ET_p) rates. ET_p is the rate of water loss from a vegetated surface when plants have unlimited water. A technically imprecise, but practically useful, application of this definition is a general maximum water use rate for vegetation as determined by the amount of energy available for photosynthesis. There are many formulas used to estimate ET_p rates. All require measurement or estimation of various amounts of climatic information to be used in a series of algebraic equations.

For the estimation of ET_p, the Thornthwaite procedure is particularly straightforward and easy to use. Air temperature is used as an index of the energy available for evapotranspiration (3) and calculations are kept relatively simple by eliminating correction factors for different vegetation types.

Previous research has documented close relationships between computed ET_p values and measured ET_a rates in nursery crops (4, 6, 8). One study conducted with container grown tropical woody plants showed correlation coefficients of 0.90 or higher between ET_p and ET_a (4). Other studies have shown strong relationships, evaluated using the chi-square test, between ET_p and ET_a in container grown tropical (6) and temperate (8) species.

The formula for monthly ET_p calculated by the Thronthwaite procedure is:

$$ET_p = 1.6 \left[\frac{10\ T_a}{I}\right]^a$$

where: ET_p = potential evapotranspiration in centimeters per month

T_a = monthly average temperature in degrees Celsius

I = annual heat index

$$= \sum_{I=I}^{12} \left[\frac{T_a}{5}\right]^{1.5}$$

$$a = 4.9 \times 10^{-1} + 1.79 \times 10^{-2}\ I - - 7.71 \times 10^{-5}\ I^2 + + 6.75 \times 10^{-7}\ I^3$$

The Thornthwaite procedure is easily used, but most growers are unfamiliar with the algebraic procedures and necessary calculations. Computer programs have been developed (7) that make the calculations automatically, but many growers may not have access to the computer hardware necessary to run the programs. The purpose of this project was to develop a simple program to compute ET_p by the Thornthwaite method that could be used on a relatively inexpensive (<$50), battery-operated, hand-held programmable calculator.

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The Program

The program involves the transcription of a computer program designed for stationary microcomputer systems (7). It was developed for use on a Hewlett-Packard[3] HP-11C programmable calculator, but with minor transcriptional changes would work on other programmable calculators as well.[4] The program is executed in 2 stages. The first stage requires the user to key in monthly average temperatures for a 12 month period. Monthly average temperatures can be measured on-site by the grower. Daily maximum plus daily minimum temperature divided by 2 equals the daily average temperature. The sum of the daily average temperatures for a month divided by the number of days in the month is the monthly average temperature. Should the grower not measure temperatures on-site, then monthly average temperature data can be acquired through the National Weather Service for many U.S. locations. The first stage of the program computes the annual heat index and the exponent necessary for ET_p calculation. The second stage of the program requires the user to again key in monthly average temperatures, but after each monthly temperature is keyed in, the monthly ET_p rate appears on the display and remains on the display until the next monthly average temperature is entered or the calculator is turned off. This program is listed in 2 versions, one that uses English system terminology and the other for the metric system. If the user wishes to use English system (degrees Fahrenheit and inches per month), then the program should be used exactly as listed. If the user wishes to use the metric system (degrees Celsius and centimeters per month), then the program should delete the lines with asterisks in the program listing (Table 2). The English system program has 98 lines and the metric system program has 72 lines. The annual heat index and exponent are computed in the metric system in both versions, however.

A Sample Run

The following example uses temperature data taken from tables in a meterology text (2). Other temperature data sources include the National Weather Service and the Cooperative Extension Service. Many growers measure and record temperature data at their nurseries. Whenever locally generated data are available, they should be used as the most accurate reflection of meteorological conditions at the growing site.

Example 1: Compute the monthly average potential evapotranspiration for Washington, DC.

1. Load a program into the calculator according to instructions on Table 1.
2. Key in the monthly average temperatures. After each entry, strike the f key, then the A key. The word ``running'' will flash briefly on the display. Then a number equivalent to the monthly heat index will flash on the display for 2 seconds. If you wish to record this number, write it down while it is flashing. Then a number will appear on the display which will be equivalent to the number of monthly average temperatures that have been entered into the calculator.

[3]Hewlett-Packard Co., Corvallis Div., Corvallis, OR

[4]A version of this program adapted for the Texas Instruments TI-66 programmable calculator is available by contacting the authors.

Table 1. Operating directions for calculating uncorrected potential evapotranspiration using the Thornthwaite procedure for use with a Hewlett-Packard HP-11C programmable calculator.

Operating Directions				
Step	Instructions	Input data	Keystrokes	Output Data
1	If the calculator has been programmed, then go to step 4. If not, then switch into program mode		g P/R	
2	Key in the program, Table 2			
3	Switch calculator into run mode		g P/R	
4	Enter the monthly mean temperature $(T_a)^z$	T_a	f A	Monthly heat index value flashing for 2 seconds, followed by n
5	Repeat step 4 for all 12 monthly mean temperature values	T_a	f A	Monthly heat index value flashing for 2 seconds, followed by n. After all 12 T_a values have been keyed in, the number 12 should appear on the display
6	After the 12 T_a values have been entered, calculate annual heat index (I)		RCL I	I
7	Calculate exponent value (a)		f B	a
8	Calculate monthly uncorrected ET_p values^z	T_a	f C	ET_p

[z]Output data will be in inches per month if input is degrees Fahrenheit and the appropriate program version from Table 2 is used (I value and exponent a will still be computed in metric, however). Output data will be in centimeters per month if input is in degrees Celsius and the appropriate program version from Table 2 is used.

3. Repeat step 2 for each of the 12 monthly average temperatures. For Washington, DC, they are as follows:

Month	(English) T_a, °F	(Metric) T_a, °C
Jan.	33.4	0.8
Feb.	35.3	1.8
Mar.	42.6	5.9
Apr.	53.3	11.8
May	63.7	17.6
June	72.2	22.4
July	76.8	24.9
Aug.	75.0	23.9
Sept.	68.1	20.1
Oct.	57.4	14.1
Nov.	45.2	7.3
Dec.	36.6	2.6

Table 2. Program listing for uncorrected potential evapotranspiration computation using a Hewlett-Packard HP-11C programmable calculator. If input units are to be degrees Fahrenheit and output in inches per month, use the program exactly as listed (I and a values will be expressed in metric units, however). If input units are to be degrees Celsius and output in centimeters per month, delete program lines 002 through 011, 069 through 078 and 092 through 097. These lines are asterisked in the table to simplify entering program commands.

Keystrokes	Display	Keystrokes	Display	Keystrokes	Display	Keystrokes	Display
f CLEAR PRGM	000-	3	025- 3	1	050- 1	* 5	075- 5
f LBL A	001-42,21,11	y^x	026- 14	×	051- 20	* 6	076- 6
* 3	002- 3	ENTER	027- 36	−	052- 30	* ×	077- 20
* 2	003- 2	•	028- 48	RCL 1	053- 45 1	* ENTER	078- 36
* −	004- 30	0	029- 0	ENTER	054- 36	1	079- 1
* ENTER	005- 36	0	030- 0	•	055- 48	0	080- 0
* •	006- 48	0	031- 0	0	056- 0	×	081- 20
* 5	007- 5	0	032- 0	1	057- 1	ENTER	082- 36
* 5	008- 5	0	033- 0	7	058- 7	RCL 1	083- 45 1
* 6	009- 6	0	034- 0	9	059- 9	÷	084- 10
* ×	010- 20	6	035- 6	×	060- 20	ENTER	085- 36
* ENTER	011- 36	7	036- 7	+	061- 40	RCL 4	086- 45 4
5	012- 5	5	037- 5	•	062- 48	y^x	087- 14
÷	013- 10	×	038- 20	4	063- 4	1	088- 1
1	014- 1	ENTER	039- 36	9	064- 9	•	089- 48
•	015- 48	RCL 1	040- 45 1	+	065- 40	6	090- 6
5	016- 5	g x^2	041- 43 11	STO 4	066- 44 4	×	091- 20
y^x	017- 14	ENTER	042- 36	g RTN	067- 43 32	* ENTER	092- 36
f PSE	018- 42 31	•	043- 48	f LBL C	068-42,21,13	* 2	093- 2
f PSE	019- 42 31	0	044- 0	* 3	069- 3	* •	094- 48
Σ+	020- 49	0	045- 0	* 2	070- 2	* 5	095- 5
g RTN	021- 43 32	0	046- 0	* −	071- 30	* 4	096- 4
f LBL B	022-42,21,12	0	047- 0	* ENTER	072- 36	* ÷	097- 10
RCL 1	023- 45 1	7	048- 7	* •	073- 48	g RTN	098- 43 32
ENTER	024- 36	7	049- 7	* 5	074- 5	g P/R	0.00

4. After the last monthly average temperature is keyed in, the number 12 should appear on the display. Strike the RCL key and then strike the 1 key. A number will appear on the display equivalent to the annual heat index. If you wish to record this value, write it down (I for Washington, DC = 57.8).
5. Strike the f key, and then strike the B key. The word "running" will flash on the display briefly, followed by a number equivalent to the exponent a in the Thornthwaite equation. If you wish to record this number, write it down (a for Washington, DC = 1.40).
6. Key in the monthly average temperatures. After each entry, strike the f key, and then strike the C key. The word "running" will flash briefly on the screen, followed by the ET_p rate for that particular month, in inches per month or centimeters per month, depending upon which program version has been used. (If desired the ET_p rate in centimeters per month can be converted into inches per month by dividing the value by 2.54).
7. ET_p rates in this example are as follows:

Month	(English) ET_p, in/mo	(Metric) ET_p, cm/mo
Jan.	0.04	0.10
Feb.	0.13	0.31
Mar.	0.65	1.65
Apr.	1.72	4.34
May	2.99	7.58
June	4.17	10.62
July	4.85	12.32
Aug.	4.58	11.63
Sept.	3.59	9.13
Oct.	2.20	5.56
Nov.	0.88	2.22
Dec.	0.20	0.52

I = 57.8
a = 1.40

8. Note the very low ET_p rates for the months with colder monthly average temperatures. In locations where monthly average temperatures fall below freezing (generally in USDA plant hardiness zone 7 or lower (1)), ET_p rates will not compute using this program without alteration. In order to use this program in those locations, substitute a monthly average temperature of 32°F (0°C) for all levels below 32°F (0°C). ET_p rates for those months will compute as 0.0 inches/mo. (0.0 cm/mo.).

Applications of the Program

This program can be used to estimate ET_p rates as a factor in irrigation planning. A hypothetical grower in the Washington, DC area for example, can determine crop water budgets more accurately by knowing that the ET_p rate for July, 4.85 in/mo. (12.32 cm/mo.) is approximately 3 times higher than the ET_p rate for April, 1.72 in/mo. (4.34 cm/mo.). The same crop grown under similar cultural conditions and at comparable stages of growth would require approximately 3 times as much water in July as in April. Where water resources are in short supply or where continual availability cannot be assured, knowledge of ET_p rates can allow effective water budgeting. Moreover, determination of ET_p rates can allow growers to analytically justify water needs to governmental agencies that regulate and allocate water resources.

Significance to the Nursery Industry

In the absence of specific data on actual evapotranspiration rates, potential evapotranspiration rates can be used as base line figures for estimating crop water use as a foundation for irrigation planning. The ready availability and low cost of programmable calculators makes this tool an attractive component in sound nursery irrigation management programs.

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