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A Computer Algorithm for Pierce's Soil Moisture Deficit

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INTRODUCTION

Pierce[2] published a method for estimating soil moisture from daily precipitation and air temperature. The details of Pierce's method were oriented toward hand calculation of a continuous record of soil moisture status. Hand calculation is feasible where records on a few stations are computed on a daily basis. For extensive calculations on several stations for which records might be available for several past years, modern electronic data processing methods would be desirable. This publication presents an algorithm which can be used as a guide for a computer program to calculate Pierce's soil moisture deficit.

To calculate the soil moisture deficit (CMD), the daily water loss is added and rainfall (adjusted for runoff) is subtracted from a previous estimate of soil moisture deficit. A starting CMD is assumed for March 31.

The formula for soil moisture deficit, CMD, is:

$$CMDi = CMD(i-1) + ET - (RF \times RA),$$

where ET is evapotranspiration, RF is rainfall for day i, and RA is the rainfall adjustment for runoff.

COMPUTATION OF WATER LOSS, ET

Pierce's formula for water loss as evapotranspiration is:

$$ET = PE \times L \times D \times C \times R,$$

where ET is evapotranspiration, PE is potential evapotranspiration, and L, D, C, and R are corrections for day length, soil dryness, crop stage, and occurrence of rainfall. PE and L are alike for all crops. D, C, and R are calculated differently for meadow, wheat, and corn.

In Pierce's publication, tables are provided for estimating each correction factor. However, all of these relationships may be expressed as polynomial functions. The functions are given below so that referring to tables is not required.

COMPUTATION OF POTENTIAL EVAPOTRANSPIRATION, PE

Potential evapotranspiration, PE, is a function of daily mean temperature, T.

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[1]Statistician, Ohio Agricultural Research and Development Center.

[2]Pierce, L. T. 1966. A method for estimating soil moisture under corn, meadow, and wheat. Ohio Agri. Res. and Dev. Center, Res. Bull. 988.

$$PE = + .46957860 \times 10^{-1} - .63813650 \times 10^{-2} \times T + .21524497 \times 10^{-3} \times T^2 - .13217495 \times 10^{-5} \times T^3$$

COMPUTATION OF DAY LENGTH CORRECTION, L

The day length correction, L, is a function of the number of days after March 31, DF.

$$L = + .10597277 \times 10 + .43458097 \times 10^{-2} \times DF - .26331625 \times 10^{-4} \times DF^2$$

COMPUTATION OF DRYNESS CORRECTION, D

Meadow and Wheat

The dryness correction, D, is a function of the previous day's soil moisture deficit, S. If any of the following conditions obtain, set D = 1.0.

1. Rainfall is measurable for 2 or more days in a row. An exception to this occurs if CMD becomes greater than that on the day immediately preceding the succession of rain. If so, apply the D correction below. For computer programming, this requires that the CMD's for rainy days be saved in case they are needed for this decision. The actual occurrence of this exception is rare.
2. The previous day's rainfall exceeds the present day's ET.
3. The previous day's soil moisture deficit is less than 2.1.

If none of the above conditions are present,

$$D = + .90356940 + .07619142 \times S - .01690485 \times S^2$$

Corn

The dryness correction for corn depends on the crop stage:

Crop Stage 1 = May 1 to June 20
Crop Stage 2 = June 21 to July 25
Crop Stage 3 = July 26 to August 31

Crop Stage 1

During crop stage 1, CMD's for four layers are computed (see CMD computation below). These are referred to as CMDi, with i = 1 to 4. The argument for computation of D is called A. The CMD's referred to are for the previous day.

If CMD1 $<$ 0.9, use CMD1 for argument A
If CMD1 = 0.9 and CMD2 $<$ 0.6, use CMD1 + CMD2 for argument A

If CMD2 $=$ 0.6 and CMD3 $<$ 1.2, use CMD1 $+$ CMD2 $+$ CMD3 for argument A

If CMD3 $=$ 1.2, use CMD1 $+$ CMD2 $+$ CMD3 $+$ CMD4 for argument A

If A $\leqslant$ 0.1, D $=$ 0.8

If A $\geqslant$ 3.5, D $=$ 0.2

If 0.1 $<$ A $<$ 3.5,

$$D = +.84361645 - .40537227 \times A + .06403068 \times A^2$$

Crop Stage 2

During crop stages 2 and 3, the dryness correction is a function of the previous day's CMD, which is referred to as A.

If A $\leqslant$ 1.30, D $=$ 1.0

If A $>$ 1.30,

$$D = +1.0839616 - .09301722 \times A + .03289310 \times A^2 - .81054533 \times 10^{-2} \times A^3$$

Crop Stage 3

If A $\leqslant$ 1.60, D $=$ 1.0

If A $>$ 1.60,

$$D = +.90130580 + .10683651 \times A - .03085144 \times A^2$$

COMPUTATION OF RAINY DAY CORRECTION, R

This correction for corn is slightly different, depending on the crop stage which is defined below. For all crops, the rainfall correction, R, is 1.0 if there is no rain, 0.6 if it is the first day of rain, 0.5 if it is the second day of rain, and 0.4 if it is the third day of rain. The exception is that if the crop is corn in the first stage and it is the third consecutive day of rain, R $=$ 0.5 instead of 0.4.

COMPUTATION OF CROP STAGE CORRECTION, C

Each crop undergoes various stages. The period of time encompassed by each stage in a "normal" year is as follows:

Meadow

Stage 1—April 1 to first cutting (June 14)

Stage 2—First cutting (June 15) to second cutting (August 2)

Stage 3—Second cutting (August 2) to September 10 and third cutting to September 30

Wheat

Stage 1—April 1 to July 19

Stage 2—July 20 to September 30

Corn

Stage 1—May 1 to June 20
Stage 2—June 21 to July 25
Stage 3—July 26 to August 31

The argument for the crop stage corrections is referred to as DS. DS is the day within the stage. Day 1 is the first day of the stage, etc.; e.g., June 20 is the sixth day of Stage 2 for meadow.

Meadow

The stages of meadow may be varied according to the cutting schedule. Stages 1 and 2 can be said to end on the dates of first and second cutting. The dates of the succeeding stages should be modified accordingly.

Two computations are possible after the second cutting. Prior to September 11, the formula labeled *First Correction* is used. If a third cutting is made, the *First Correction* formula is repeated. After September 11, if no third cutting has been made the *Second Correction* should be applied. If a third cutting was made, both corrections should be computed and the one yielding the lesser value applied.

Stage 1

If $DS \leqslant 34$,

$$C = +.65102943 + .16657633 \times 10^{-1} \times DS - .18833841 \times 10^{-3} \times DS^2$$

If $DS > 34$, $C = 1.00$

Stage 2

If $DS \leqslant 34$,

$$C = +.37367648 + .26001676 \times 10^{-1} \times DS - .30798504 \times 10^{-3} \times DS^2$$

If $DS > 34$, $C = 0.9$

Stage 3

First Correction

If $DS \leqslant 30$,

$$C = +.30599885 + .28791356 \times 10^{-1} \times DS - .42592710 \times 10^{-3} \times DS^2 - .88408497 \times 10^{-6} \times DS^3$$

If $DS > 30$, $C = 0.76$

Second Correction

Note that argument DS is redefined as days after September 10. Apply as indicated above:

$$C = +.76500567 - .40075733 \times 10^{-2} \times DS - .17992436 \times 10^{-3} \times DS^2$$

Wheat

Stage 1

If $DS \leq 19$,

$$C = +.76869130 + .28726864 \times 10^{-1} \times DS - .13452242 \times 10^{-2} \times DS^2 + .23807893 \times 10^{-4} \times DS^3$$

If $19 < DS \leq 68$, $C = 1.0$

If $68 < DS \leq 106$,

$$C = -2.9997770 + .02553280 \times DS + .27281920 \times 10^{-2} \times DS^2 - .46881280 \times 10^{-4} \times DS^3 + .20456088 \times 10^{-6} \times DS^4$$

If $DS > 106$, $C = 0.34$

Stage 2

If $DS \leq 39$,

$$C = +.42506661 + .14145933 \times 10^{-1} \times DS + .14451412 \times 10^{-3} \times DS^2 - .55425944 \times 10^{-5} \times DS^3$$

If $39 < DS \leq 53$, $C = 0.88$

If $53 < DS \leq 73$,

$$C = +.39666400 + .21969391 \times 10^{-1} \times DS - .24409332 \times 10^{-3} \times DS^2$$

If $DS > 73$, $C = 0.7$

Corn

Stage 1

$$C = 1.0$$

Stage 2

If $DS \leq 34$,

$$C = +.47321548 + .41471248 \times 10^{-1} \times DS - .11891484 \times 10^{-2} \times DS^2 + .12391975 \times 10^{-4} \times DS^3$$

If $DS > 34$, $C = 1.0$

Stage 3

If $DS < 26$, $C = 1.0$

If $DS \geq 26$,

$$C = -14.420280 + .14595113 \times 10 \times DS - .44853892 \times 10^{-1} \times DS^2 + .44203238 \times 10^{-3} \times DS^3$$

COMPUTATION OF ADJUSTED RAINFALL, RF X RA

The adjustment which is applied to the daily rainfall value, RF, is used to compensate for different runoff rates in the three crops. RF and crop are used as arguments for RA as follows:

	Meadow	Wheat	Corn
$RF \leqslant 1.0$	1.0	1.0	1.0
$1.0 < RF \leqslant 2.0$	0.9	0.9	0.75
$RF > 2.0$	0.75	0.75	0.50

COMPUTATION OF SOIL MOISTURE DEFICIT, CMD

A value of CMD may be assumed for March 31. Pierce assumes this to be 0. Values for minimum and maximum other than those of Pierce may also be substituted.

Meadow and Wheat

$$CMDi = CMD(i-1) + ET - (RF \times RA)$$

Minimum and maximum allowed values for CMD are — 1.0 and + 8.0. Accumulation starts April 1 and ends September 30.

Corn

Accumulation starts May 1 and ends August 31.

Stage 1

CMD's for four separate soil layers are calculated and accumulated for corn during Stage 1. Each of the four CMDi's are limited to a certain minimum and maximum. Any excess (EXI) above or below the limits is applied to CMDI + 1.

$CMD1_j = CMD1_{j-1} + ET - (RF \times RA)$, MinMax = 0, + 0.9; therefore EX1 = CMD1 given $CMD1_{min}$; EX1 = CMD1 — 0.9 given $CMD1_{max}$

$CMD2_j = CMD2_{j-1} + EX1$, MinMax = — 0.1, + 0.6; if result is negative, add 0.01

$CMD3_j = CMD3_{j-1} + EX2$, MinMax = — 0.3, + 1.20; if result is negative, add 0.01

$CMD4_j = CMD4_{j-1} + EX3$, MinMax = — 0.3, 00; if result is negative, add 0.01

CMD for Stage 1 = CMD1 + CMD2 + CMD3 + CMD4

Stage 2

$$CMDi = CMD(i-1) + ET - (RF \times RA)$$

Minimum and maximum allowed values for CMD are — 0.6 and 5.0.

Stage 3

$$CMDi = CMD(i-1) + ET - (RF \times RA)$$

Minimum and maximum allowed values are — 1.0 and + 6.0.