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TRANSPIRATION AND EVAPOTRANSPIRATION FROM MAIZE AS RELATED TO LEAF AREA INDEX*

MAHDI AL-KAISI, LYNN J. BRUN and JOHN W. ENZ

Department of Soil Science, North Dakota State University, Fargo, ND 58105 (U.S.A.)

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ABSTRACT

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Evapotranspiration and transpiration from maize (*Zea mays* L.) were measured with precision weighing lysimeters in 1983 and 1984. Climatic parameters were measured to calculate potential evapotranspiration, while leaf area index was measured twice weekly. Crop coefficients were determined from daily values of evapotranspiration (or transpiration)/potential evapotranspiration. Non-linear models were tested and showed that 72-86% of the variation in crop coefficient for evapotranspiration could be described knowing leaf area index. Model testing with transpiration showed that 90-95% of the variation in crop coefficient could be described knowing leaf area index.

INTRODUCTION

Timely application of water is an important aspect of efficient crop production with irrigation. Ritchie (1971) stated that evaporative flux from annual row crops grown from seedlings to maturity is influenced by micrometeorological, plant and soil factors. Ritchie and Burnett (1971) found that leaf area index (*LAI*) and dry matter were applicable factors in defining a critical threshold canopy characteristic where plant factors have a small influence on evaporative flux. The ratio transpiration/evapotranspiration (*T*/*ET*) was shown to be related to *LAI* by Brun et al. (1972). A number of researchers (Kanemasu et al., 1976; Tanner and Jury, 1976; Rosenthal et al., 1977) have used *LAI* along with microclimatic and soil factors to predict *ET* and/or *T*.

Prediction of *ET* as a function of crop stage or *LAI* is an important aspect of predicting crop water use and, thus, the need for irrigation. This typically involves the development of a crop coefficient which is the ratio *T* or *ET*/

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potential evapotranspiration (*PET*). The crop coefficient is typically related to the stage of crop development or *LAI*.

The purpose of this study was to determine crop coefficients based on *T* and *ET* for well-watered maize [*Zea mays* (L.) Pioneer 3978] as related to *LAI*.

MATERIALS AND METHODS

The study was conducted during the summers of 1983 and 1984 at the Microclimate Research Station of the North Dakota State University Main Experiment Station at Fargo. Two precision weighing lysimeters (Brun et al., 1983, 1985) were used to monitor *T* and *ET*. Each lysimeter has dimensions of $(1.52\ \mathrm{m})^3$ and is sensitive to weight changes equivalent to 0.2 mm of water. The lysimeters contained Fargo–Ryan silty clay (fine, montmorillonitic, frigid, Vertic Haplaquoll with a leached and degraded natric horizon). An access tube in each lysimeter was used to determine volumetric water content by neutron attenuation.

The soil on each lysimeter was tilled by hand (spading and raking) leaving a bare, residue-free surface. The area outside the lysimeters was tilled with conventional farm equipment.

A cover, designed to prevent evaporation (*E*) from the soil, was installed on one lysimeter on 20 June 1983 and 22 June 1984, shortly after maize emergence. In 1983, the cover was constructed using 0.1-mm black polyethylene and in 1984 it was constructed of plywood and neoprene rubber. Individual maize plant stems protruded through the sealed openings in the covers. Both covers were sloped to shed precipitation. Plastic tubing was installed under the covers for applying irrigation water. The lysimeter with bare soil was irrigated with an overhead sprinkler. Each lysimeter was irrigated whenever 50% of the available water in the root zone was depleted.

Two rows of maize were planted on each lysimeter on 23 May 1983 and on 15 May 1984, spaced 76 cm apart. Shortly after emergence, a population of 16 plants was established on each lysimeter (69 252 ha^{-1}) by hand thinning. Fertilizer was broadcast in recommended amounts so as not to be a yield limiting factor.

Climatic data were recorded over a grassed surface 40–50 m north of the lysimeter area. A programmable data acquisition system was used to obtain hourly and daily totals of solar radiation using an Epply black and white pyranometer. Air temperature was recorded hourly using a thermocouple in a standard instrument shelter. *PET* was calculated using the Jensen–Haise equation (Jensen and Haise, 1963). This equation is expressed in SI units as

$$PET = R_s \cdot (0.025T + 0.08)$$

where T is the mean daily air temperature in °C, R_s is the daily total solar radiation in units equivalent to mm of water, and *PET* is in mm day^{-1}.

LAI was measured twice per week on four selected plants on each lysimeter. The length (*L*) and maximum width (*W*) of each leaf were measured and the expression leaf area $=0.74LW$ presented by Palaniswamy and Gomez (1974), was used to calculate the area of each leaf. The total of all leaves from the four plants was used to calculate the *LAI* based on the surface area represented by the plants.

Maize was harvested on 18 September in 1983 and on 17 September in 1984. Growing season *ET* is based on the period from planting until harvest.

RESULTS AND DISCUSSION

Sixty values of *T* or *ET* and *LAI* were available for analysis from 1983 and 1984 data: 32 for the cover treatment and 28 with bare soil. All days on which *LAI* was measured were utilized except that data were eliminated after about 20 August when leaf senescence and reduction in *LAI* were observed. In addition, a dummy data point, $T=0$ for $LAI=0$, was included for the cover treatment.

Daily *E* or *ET*, as related to *LAI*, are illustrated in Fig. 1. We observe that *T* and *ET* increase as *LAI* increases. The scatter is caused by daily variation in *PET*. Also, *T* appears to be less than *ET* for small values of *LAI*. Maximum *LAI* in 1983 was 3.23 and 3.72, and in 1984 it was 3.15 and 3.07 for the covered and bare soil treatments, respectively. Crop coefficients, *T*/*PET* or *ET*/*PET*, were calculated from daily measurements of *T* (covered lysimeter) and *ET* (lysimeter with bare soil) and calculated *PET*.

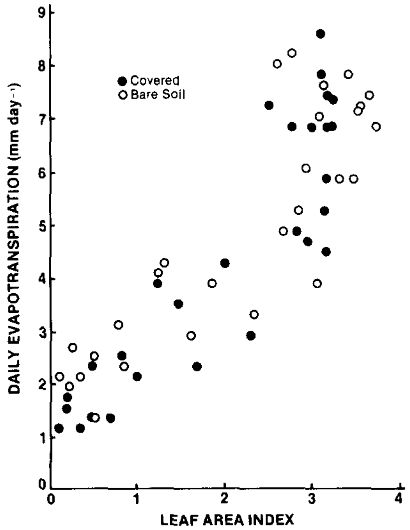

Fig. 1. Daily water loss from covered and bare soil as related to *LAI*.

The models in Table 1 were tested with the non-linear SAS Procedure NLIN (Helwig and Council, 1979). Previous experiments (Ritchie and Burnett, 1971) and experience indicate the crop coefficient versus *LAI* should be curvilinear and approach a value of 1 when *LAI* is ~3. Calculated statistics are found in Table 2 and corresponding parameters in Table 3.

Model 1 was expected to work well for the covered treatment where the crop coefficient should be zero for $LAI = 0$. This was verified by the R^2 value of 0.90 (Table 2). This model did not work as well for the bare soil treatment because of soil evaporation at small *LAI*s. Multiplying Model 1 by a factor C (Model 2) did not improve the R^2 values meaningfully.

The addition of a constant A or intercept term was expected to improve the fit for the bare soil treatment by providing a value for soil evaporation, especially at low *LAI*. The R^2 value increased from 0.72 to 0.82 comparing Model 1 to Model 3. No improvement resulted for the covered treatment with Model 3.

Models 4 and 5, second and third order equations, respectively, gave very small increases in R^2 values compared to Model 3. The parameter values for Models 1–5 are listed in Table 3.

TABLE 1

Equations used for fitting the data

Model No.	Right hand side of equation for crop coefficient[a]
1	$(1-e^{-B(LAI)})$
2	$C(1-e^{-B(LAI)})$
3	$A+(1-e^{-B(LAI)})$
4	$A+B(LAI)+C(LAI)^2$
5	$A+B(LAI)+C(LAI)^2+D(LAI)^3$

[a] A, B, C and D are parameters.

TABLE 2

Statistical analysis for the models of Table 1

Model No.	df	Model SS		Residual and error MS		F		R^2	
		Covered	Bare	Covered	Bare	Covered	Bare	Covered	Bare
1	1	3.37771	1.36135	0.012	0.019	281.4	71.1	0.90	0.72
2	2	3.45090	1.36140	0.010	0.020	172.5	34.0	0.92	0.73
3	2	3.40693	1.55415	0.011	0.013	154.9	59.8	0.91	0.82
4	2	3.50903	1.76843	0.008	0.011	219.3	80.4	0.94	0.85
5	3	3.54649	1.77427	0.007	0.012	168.9	49.3	0.95	0.86

TABLE 3

Parameter values for all models with statistics as indicated in Table 2

Model	Treatment	Parameter			
		A	*B*	*C*	*D*
1	Covered	-	0.586	-	-
1	Bare	-	0.688	-	-
2	Covered	-	0.230	1.749	-
2	Bare	-	0.686	1.001	-
3	Covered	0.059	0.488	-	-
3	Bare	0.239	0.319	-	-
4	Covered	0.093	0.255	0.002	-
4	Bare	0.274	0.196	−0.0004	-
5	Covered	0.056	0.518	−0.228	0.048
5	Bare	0.309	0.069	−0.082	−0.014

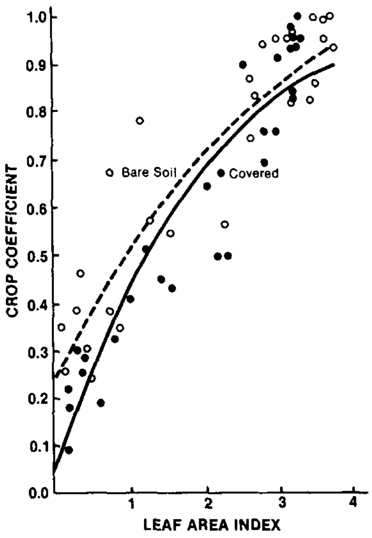

Fig. 2. Crop coefficient for covered and bare soil as related to *LAI* as calculated by Model 3.

The results for Model 3 are illustrated in Fig. 2. The difference in the curves represents the *E* component of *ET*. For small *LAI*, the crop coefficient on the bare treatment is 3–4 times greater than for the covered treatment. However, when an *LAI* of 2 is reached the difference is very small with the crop coefficient for the bare treatment only ∼ 5% greater than for the covered treatment. Thus, the *E* component under a full canopy is quite small, even with the well-watered conditions in this experiment.

The covered treatment resulted in a 16% increase in water use efficiency for

TABLE 4

Average yields and *ET* for the 1983 and 1984 growing seasons

Treatment	*ET* (cm)	Yield ($kg\ ha^{-1}$)		Water use efficiency ($kg\ ha^{-1}\ cm^{-1}$)	
		Grain	Total dry matter	Grain	Total dry matter
Covered	42.16	11 289	17 239	268	409
Bare	44.31	10 238	16 190	231	365

grain yield and a 12% increase in water use efficiency for total dry matter (Table 4). Yields were also somewhat higher for the covered treatment although the reason for this is not obvious. It may be a reflection of more favorable water content at or near the surface because of no *E* loss.

The results indicate that most of the variation in crop coefficient values can be described if *LAI* is known. Higher R^2 values are obtained with the covered treatment because variation in *E* due to differences in water content at the surface is eliminated. This is most significant early in the growing season when *LAI* is <1.

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