Study on Evapotranspiration Coefficient of Corn

Charles C.C. Shih, Tom B.C. Chang, and Shan-shin Chiang

ABSTRACT

The defination of evapotranspiration coefficient is the ratio of the actual evapotranspiration of crop (ET) to the reference evapotranspiration (ETr), that is the index of crop water consumption during growing period. Evapotranspiration is the combination of evaporation from soil surface and transpiration from plants. This paper used the experimental data from field, lysimeter and auto rainshelter lysimeter to get the actual evapotranspiration during 1986 to 1988. The reference evapotranspiration are determined by potential ET (ETp) which are estimated by the Penman modified model (Kcp) and A-class pan evaporation (Kca). Results showed that the average corn Kcp was 0.66 in growing season and 0.65 based on growing-degree-days in spring corn, and 0.71, 0.57, in autumn corn, respectively.

INTRODUCTION

Domestic use of water and industrial water are increased gradually in recent years in Taiwan. A large pressure is coming to agricultural use of water. The most of the agricultural water are used for paddy rice and upland crops irrigation, to supply irrigation water for paddy rice irrigation is reduced recent years, because less area is planted with paddy rice and the upland crop plantation is increased gradually. So that, in order to decrease the agricultural water, we have to decrease the irrigation water from upland crop irrigation. Corn is the main crop in upland crop in Taiwan now, in order to economic use of water resources, the irrigation requirement of corn has been studied many years. So, the authors take the subject of evapotranspiration coefficient of corn for studying. The experiments were taken from Hsuehchia, Tainan, in 1986 to 1988 for three years, it took from field, lysimeter and auto rainshelter lysimeter, then, use the meteorological data into the Penman equation during growing season for calculating the crop evapotranspiration coefficient of corn Kc.

Crop evapotranspiration coefficient is the ratio of actual evapotranspiration (ET) to reference ET (ETr), it is the index of crop consumptive use of water during growing season. ETr refer to alfalfa or grass in a most good growing condition, which the consumptive use of crop is the maximum during growing season. Evapotranspiration is the sum of crop transpiration and evaporation from crop adjacent soil and water surface, the two items are very hard to separate.

THE FACTORS INFERENCE TO EVAPOTRANSPIRATION

Because of the meteorological factors of temperature, wind, radiation etc. produce most physical variation in the air which influence the plants and earth surface. There are four types of lost water which in earth surface and in soil root zone such as (i) evaporation: the process from the liquid to gas; (ii) transpiration: the process from plant's metabolism, breath to atmosphere; (iii) sublimation: the process from solid matter to vapor; and (iv) incorporation: it is one part of organization of plant physiology.

Evapotranspiration may be varied by crop growing environment, crop growing stage, evaporation in the atmosphere plant physiology, degree of coverage by plant leaves and stems, evaporation from soil surface etc. So that, four basic factors influence the evapotranspiration are (i) meteological factors: it includes sun shine, temperature, humidity, wind velocity, evaporation, etc. which are influenced by the growing season, latitude and topography; (ii) soil factors: the main factors to influence evapotranspiration are moisture content in soil, water holding capacity and the capillary water moves from root zone. If the soil moisture tension larger than absorption ability of roots, any high moisture content in proper weather condition the soil can not supplied the water for evaporation; (iii) cultivation method and factors of crop: consumptive use of crop is different in growing stage, the density of crop cultivation is also influenced consumptive use of crop; (iv) irrigation method: surface irrigation may be larger evaporation on soil surface; wind velocity may influenced evaporation when we apply sprinkler irrigation.

BASIC PHYSICAL PHENOMENON OF EVAPOTRANSPIRATION

Three main basic matchmaker of evapotranspiration are soil, plant and air. Soil is a large water tank to supply water to plants, from there, the total surface of roots and the coefficient of hydraulic conductivity are the main factors determined of crop consumptive use of water. Transpiration is the water from roots pass through stems up the leaves and it becomes vapor into atmosphere. Usually, the vapor spread into atmosphere from stomata which are about 90 to 97%. Therefore, in order to understand the process of evapotranspiration, the physical phenomenon on soil evaporation and transpiration have to be discussed in detail.

(1) The phenomenon of evaporation:

There are two basic theory for discussing evaporation from water surface, one is the vapor mass transfer process equation—diffusion method or aerodynamic theory. The another theory is to neglect the instantaneous dynamic process and utilize the theory of energy flux balance to get necessary energy of evaporation.

Because of solar radiation and the influence by topography, air flux is a turbulent condition in the earth surface. Consider one dimension coordinate, assume evaporation is varied along the vertical elevation, the rate of evaporation in a unit area is

$$E = - \rho_{,} K_w \frac{d\bar{q}}{dz} \qquad (1)$$

where E is the evaporation flux ($g/cm^2/sec$); Δ is the density of water (g/cm^3); Kw is the diffusion coefficient of vapor transfer (cm^2/sec); q is the instantaneous specific humidity of atmosphere; and z is the height (cm).

Consider vapor transfer in atmosphere process, there are many unknown which have to get from experiment, therefore, most of them are utilized meteorological factors which adopt statistics regression method to get the parameters. Dalton was the earliest to use the empirical equation to solve the value of evaporation (2) to solve the value of evaporation.

$$E = (a + b\,\overline{u})\,(\overline{\epsilon_s} - \overline{\epsilon_d}) \tag{2}$$

where a, b correction coefficient based on local condition, u wind velocity at 2 meter heigh from ground (cm/sec), ($\overline{\epsilon_s}$—$\overline{\epsilon_d}$) difference of vapor pressure (mbar)

In another way, utilize the principle of energy conservation, consider the energy balance in the field, the energy variation can be written a mathematic equation as below:

$$Q_{net} = Q_E + Q_H + \Delta Q_s + \Delta Q_p + \Delta Q_A \quad (W/m^2) \tag{3}$$

where Q_{net} eject energy to the field
Q_E evaporation latent heat
Q_H air convection sensible heat
ΔQ_s variation of storage energy in the field
ΔQ_p lost energy from photosynthesis
ΔQ_A conduction heat of air convection in forizonal direction

Penman combined the two theory above and develop a mixed model, the basic equation as below:

$$\lambda E = \frac{\Delta (R_n + G) + \tau E_a}{\Delta + \tau} \tag{4}$$

where λ : vapor latent heat (cal/g)
Δ : curve slope, satuated vapor pressure to temperature (mvar/°C)
τ : humidity constant mbar/°C
R_n : net radiation rate ($cal/cm^2/day$)
G : heat conduction rate of soil ($cal/cm^2/day$)

(2) The phenomenon of transpiration:

Many factors influence transpiration, they are (i) humidity in atmosphere: if large humidity in atmosphere it will be interfered with transpiration, but the largest influence transpiration is not absolute humidity, but relative humidity; (ii) temperature: when temperature increase, the activity of root and stomata are sprightly, it can be got larger transpiration, but transpiration influenced by temperature due to relative humidity, in another words, when increase temperature and decrease humidity, the temperature influenced transpiration mostly; (iii) movement of air: larger transpiration when the saturate vapor around stomata which are moved by air and brought dry air; (iv) light: light is the key point of stomata open and close, it influences transpiration indirectly; sun shine can influence transpiration about 30% on leaves; (v) reaction by dissolve water: if water solution has high acid in soil, there is a larger transpiration; otherwise low transpiration in alkali soil; (vi) number and size of stomata: many and large size of stomata in leaves may get larger transpiration, usually, the most of stomata under leaf surface, but no stomata under leaves which float on water surface, therefore the main transpiration function in up leaf surface only; (vii) shape and organization of plant: large surface area has a large transpiration, if plant surface has cork layer or cutting layer and closed with wax or fur, there are a little transpiration; (viii) growing stage: usually, new leaves, new stems and flower is opening, transpiration is in maximum period; (ix) kinds of plant: different kind of plant which grows in the same environment, the consumptive use of water is different in an unit time.

ANALYZE AND DETERMINE EVAPOTRANSPIRATION COEFFICIENT OF CORN

The analyze data come from Hsuehchia Experimental Station in the area of Chianan Irrigation Association during 1986 to 1988 for three years. There are three cultivation in spring and two in autumn of corn. They are planted in field, lysimeter and under auto rain shelter lysimeter at the same time. They are four treatments and three repetitions as below:

A: one time of irrigation at flourish period;
B: two time of irrigation at flourish and fruit period;
C: irrigation when soil moisture drop to 50% available moisture;
D: no irrigation at all.

The soil texture is silty loam, field capacity 21.07% (by weight), wilting point 6.42% and apparent specific gravity 1.52. Irrigation is controlled by soil moisture. Using oven dry method to determine the soil moisture and take soil sample once a week before irrigation and compute effective rainfall. After the experiments, use the water balance concept to calculate evapotranspiration as below:

$$ET = I + R + G - DI - DR \pm \Delta M \qquad (mm) \tag{5}$$

where I is the irrigation water; R is the rainfall; G is the supply capillary water from ground water, the ground water table about 3 meters in the experiment field, i.e. G is assumed to be zero; DI is the deep percolation water by irrigation; DR is the runoff water; and Δ M is the variation of soil moisture.

Evapotranspiration in the experiment of auto rain shelter lysimeter, because of no rainfall is occurred, it may be used the equation as below:

$$ET = I - DI - DR \pm \Delta M \qquad (mm) \tag{6}$$

Because it can not be measured rainfall and deep percolation, therefore, evapotranspiration can be calculated by the variation of soil moisture from before and after irrigation such as

$$ET = \frac{(W_s - W_a)\, A_s\, D}{100} \qquad (7)$$

where W_s is the soil moisture in percent by weight after irrigation or rainfall; W_a is the soil moisture in percent by weight before irrigation; and A_s is soil bulk density; D is the depth of root zone, assume 40 centimeters. Effective rainfall is calculated by equation (7) also. Up limit of irrigation water is assumed at field capacity.

Wright discussed many coefficients of crop, to estimate evapotranspiration. The definition of crop coefficient is the ratio of actual evapotranspiration (ET) to reference evapotranspiration (ETr).

$$K_c = ET / ET_r \qquad (8)$$

ETr is calculated by corrected Penman equation, the potential ET is calculated as below:

$$ET_r = \frac{\Delta Rn + 15.35\tau\,(a+bu)\,(\epsilon_s - \epsilon_d)}{\lambda\,(\Delta + \tau)} \qquad (9)$$

where a, b are the coefficients of wind velocity, the values are 1, 0.01 respectively, the other parameters are the same in equation. If the crop coefficient is calculated from potential ET, we said Kcp; if the coefficient is calculated from evaporation from A-class pan, the corn coefficient is assigned Kca.

Besides, growing-degree-days may also be discussed crop coefficient. This method uses accumulate average temperature in growing season to estimate crop growth, it is used widely in the tempered and frigid zones. The calculate equation is below:

$$GDD = \frac{T_{max} + T_{mix}}{2} - 10 \qquad (10)$$

where T_{max} and T_{min} are daily temperature maximum and minimum,(°C) assume basic temperature 10°C in corn.

The results of crop coefficients are shown Table 1, 2 and Fig.1 to 4 which are used the methods of Penman (Kcp) and A-class pan (Kca). The average crop coefficient of corn with the methods of Penman and A-class pan in spring and autumn are shown on Table 1 and Fig.1. The average coefficient Kcp and Kca are 0.63 and 0.7 respectively in spring corn. The values of 10 days average Kcp and Kca are larger than which from Penman method, the maximum

coefficients are in 60 to 90 days after planting and drop down near harvest, it is corresponding to the crop physiology. The average coefficients in autumn corn are 0.63 and 0.79 in Penman and A-class pan methods respectively, but the average coefficient is the same in Penman method with spring corn, and the average coefficient of A-class pan larger than 13% which in Penman method to compare from spring corn. The average crop coefficients corn by the methods of growing-degree-days and A-class pan of spring and autumn are shown on Table 2 and Fig. 3 and 4. The average coefficients are 0.62 and 0.68 in spring corn and 0.5 and 0.64 in autumn corn respectively. The coefficient in spring corn is larger 24% to compare which in autumn. When growing-degree-days is from 900 to 1200 C, the maximum coefficients range from 0.82 to 0.84 in spring corn and 0.74 to 0.76 in autumn respectively,
the same tendency in the method of A-class pan, but the coefficients range are difference, 0.92 to 0.9 in spring corn, and 0.93 to 0.96 in autumn.

CONCLUSION

This paper is started from theoretical analysis from Penman equation and growing-degree-days theory, then take experiments to get actual evapotranspiration of corn in field, lysimeter, and auto rain shelter lysimeter from 1986 to 1988 for three years. Use the two methods above and A-class pan method to calculate evapotranspiration coefficient of corn. The results are as below:

1. Actual consumptive use of corn was controlled by water depletion method, use oven dry to calculate soil moisture after irrigation and rainfall.
2. Use Penman, A-class pan methods to calculate reference evapotranspiration, then to get three kinds of evapotranspiration coefficients to compare each other.
3. The average evapotranspiration coefficients are 0.63 and 0.70 with the methods of Penman and A-class pan in spring corn and 0.63 and 0.79 in autumn corn respectively. The maximum coefficient is ranged in 60 to 90 days after planting in spring corn, but 50 to 80 days after planting in autumn.
4. The average evapotranspiration coefficients are 0.62 and 0.68 with the methods of growing-degree-days and A-class pan in spring corn respectively, and 0.5 and 0.64 in autumn corn respectively. The maximum coefficients are ranged in 900 to 1200°c both in spring and autumn corn.
5. Evapotranspiration curves are very close in both methods of Penman and A-class pan in spring corn, but it is difference in autumn.

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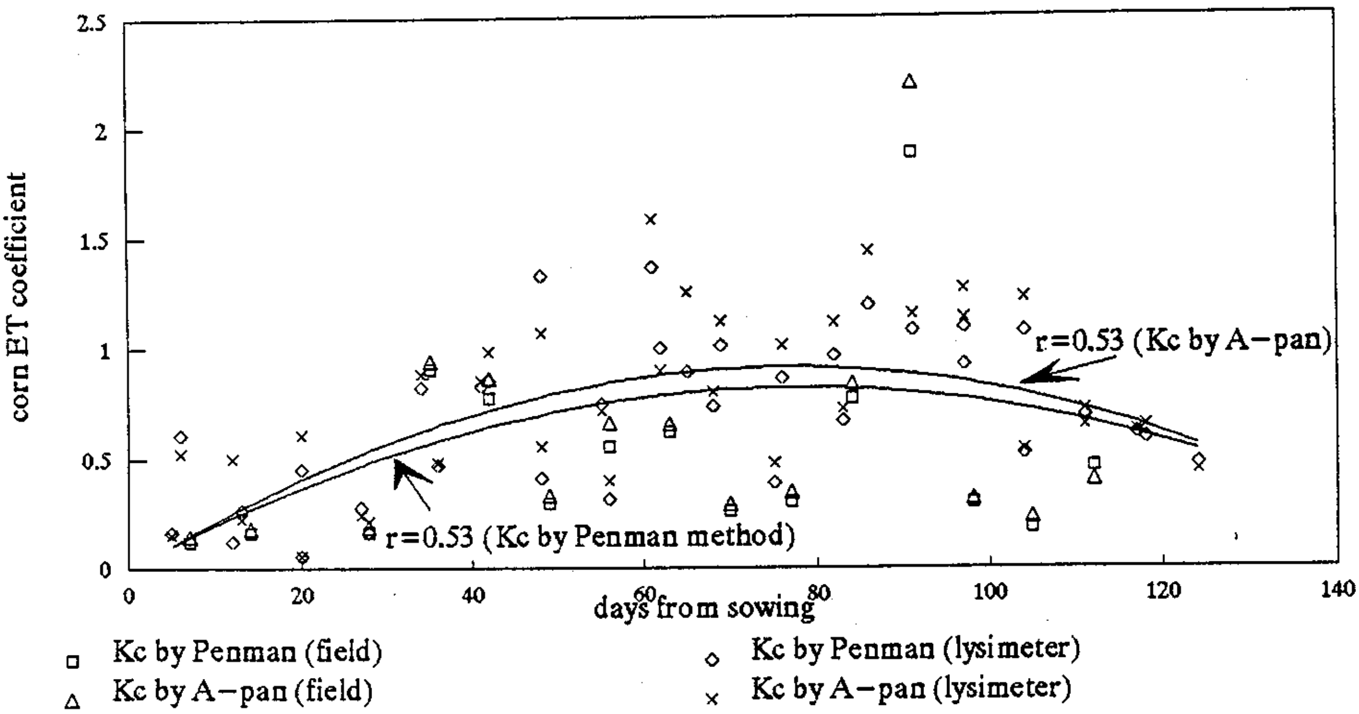

Figure 1: Evapotranspiration coefficients for spring corn as related to days since planting

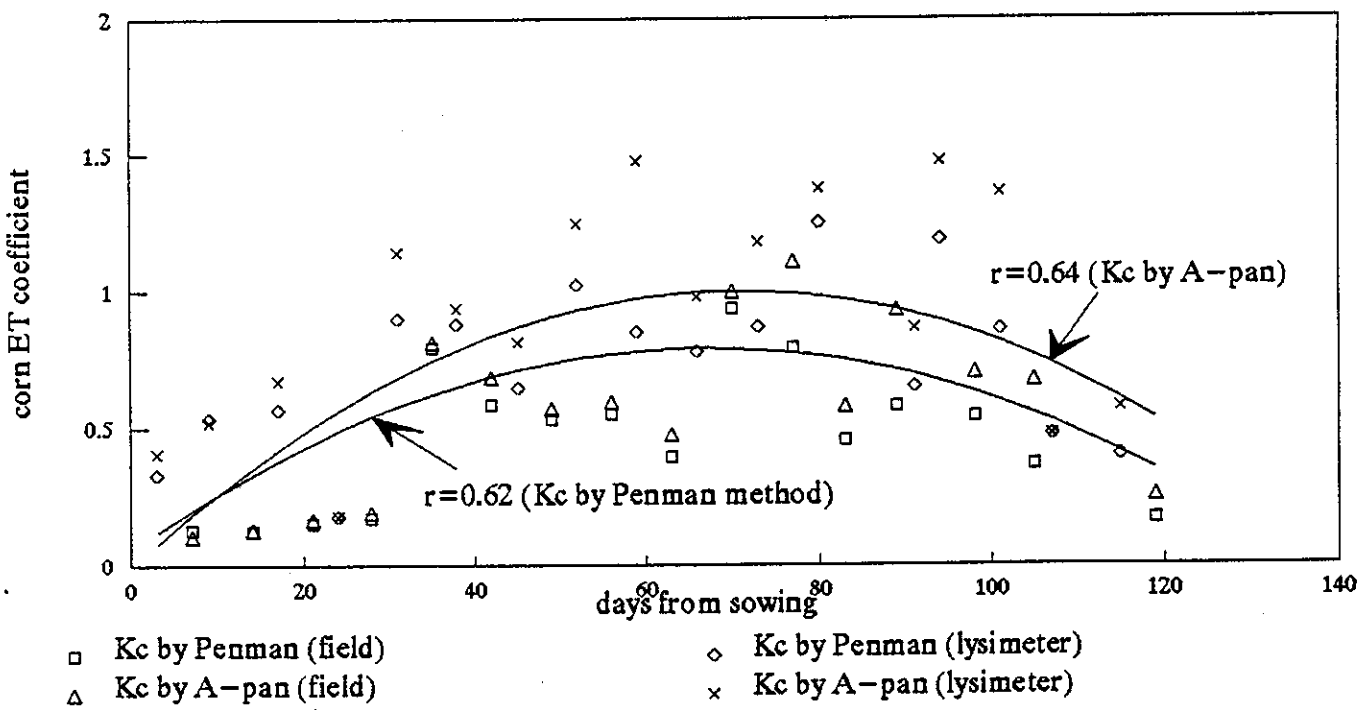

Figure 2: Evapotranspiration coefficients for autumn corn as related to days since planting

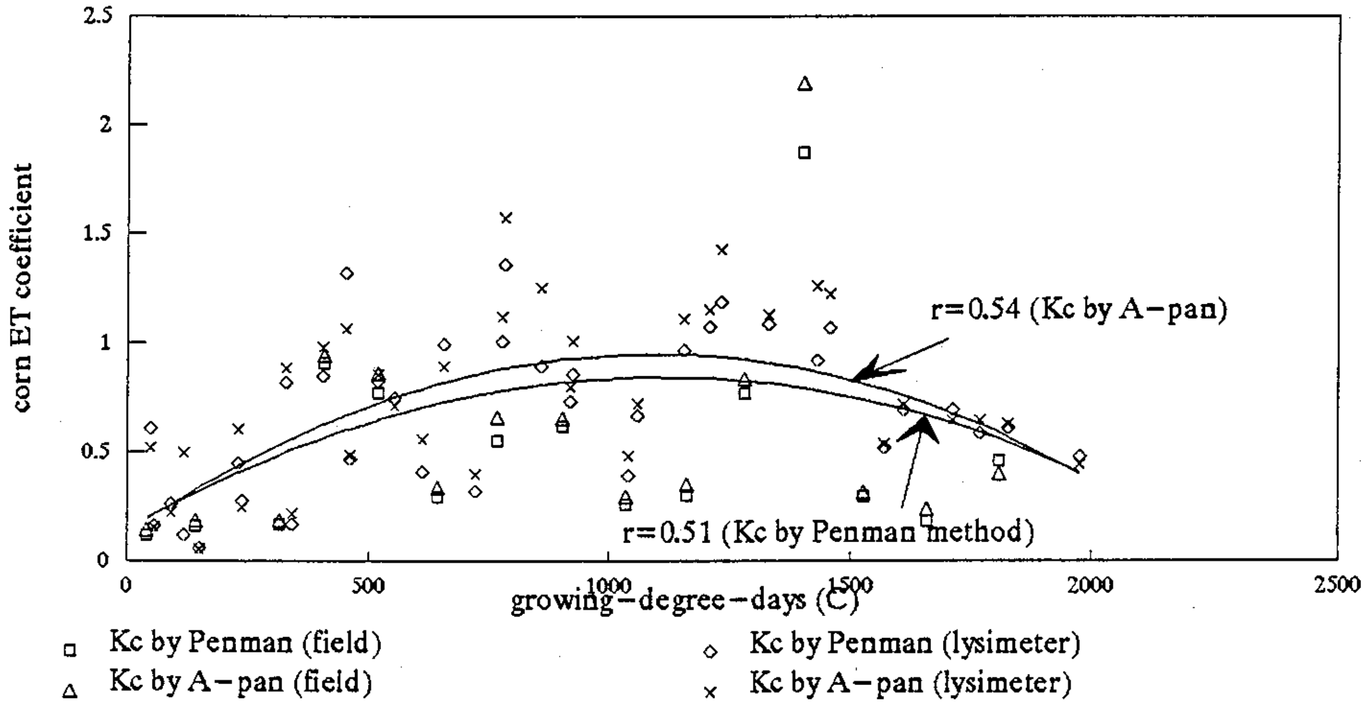

Figure 3: Evapotranspiration coefficients for spring corn as related to growing-degree-days

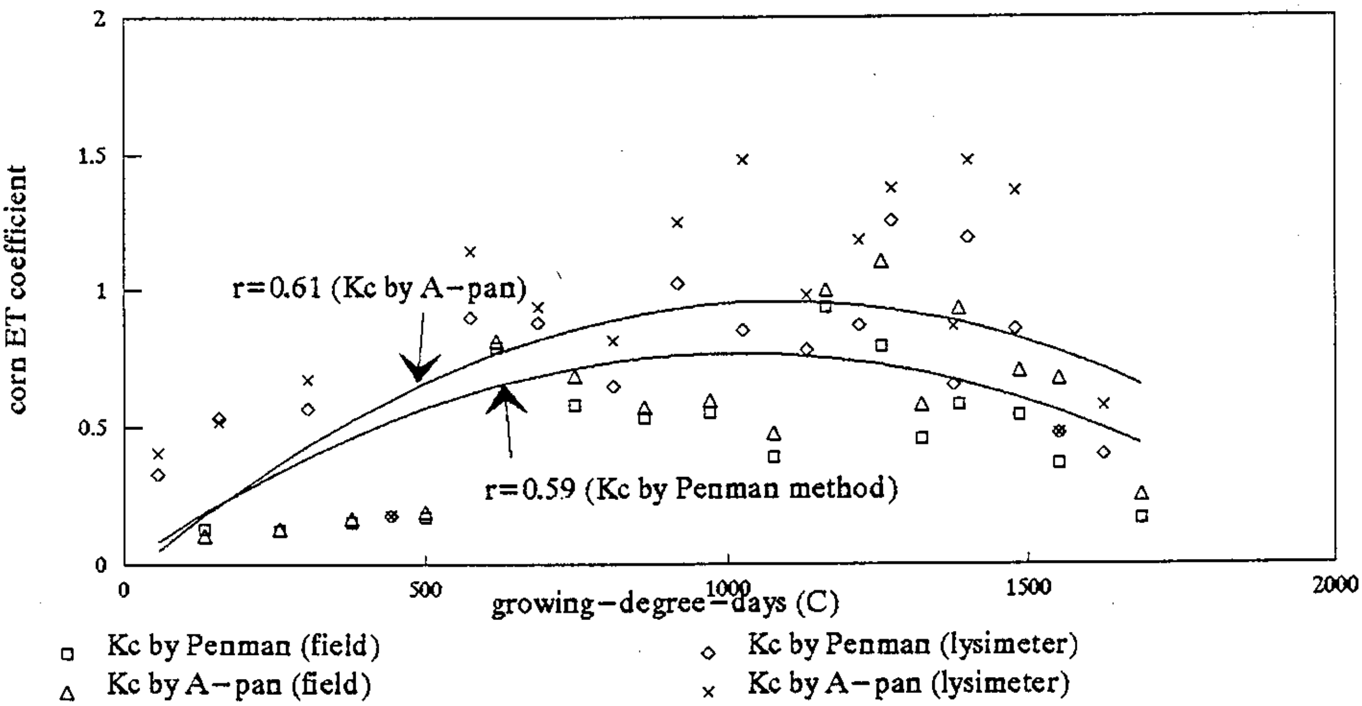

Figure 4: Evapotranspiration coefficients for autumn corn as related to growing-degree-days

Table 1: The average crop coefficients estimated by Penman and A-class pan methods for spring and autumn corn as related to days since planting

days from sowing		10	20	30	40	50	60	80	90	100	mean
spring	Kcp	0.2	0.37	0.51	0.62	0.71	0.77	0.81	0.79	0.74	0.63
corn	Kca	0.21	0.4	0.57	0.7	0.79	0.86	0.9	0.88	0.82	0.7
autumn	Kcp	0.26	0.43	0.57	0.75	0.79	0.79	0.77	0.71	0.61	0.63
corn	Kca	0.26	0.48	0.67	0.81	0.92	0.98	0.99	0.93	0.83	0.79

note: Kcp -- crop coefficient by Penman method
Kca -- crop coefficient by A-class pan method

Table 2: The average crop coefficients estimated by Penman and A-class pan methods for spring and autumn corn as related to growing-degree-days (C°).

growing degree-days		100	300	500	700	900	1100	1200	1600	1800	mean
spring	Kcp	0.27	0.47	0.63	0.75	0.82	0.84	0.83	0.69	0.56	0.62
corn	Kca	0.27	0.52	0.71	0.84	0.92	0.94	0.93	0.76	0.59	0.68
autumn	Kcp	0.14	0.39	0.57	0.69	0.76	0.76	0.74	0.52	0.31	0.5
corn	Kca	0.12	0.43	0.66	0.83	0.93	0.96	0.95	0.74	0.53	0.64

note : Kcp -- crop coefficient by Penman method
Kca -- crop coefficient by A-class pan method