FINAL REPORT

ON

DETERMINATION OF EVAPOTRANSPIRATION BY USING CLIMATIC FACTORS

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DETERMINATION OF EVAPOTRANSPIRATION BY USING CLIMATIC FACTORS

SUBMITTED TO

FACULTY OF AGRICULTURAL PRODUCTION

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BY

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INTRODUCTION

From irrigation point of view, evapotranspiration or consumptive use is the sum of two terms, evaporation and transpiration. Evaporation, which is water evaporating from adjacent soil, water surfaces or from the surfaces of leaves of plants. Transpiration, which is water entering plant roots and used to build plant tissue or being passed through leaves of the plants into atmosphere. Water deposited by dew, rainfall and sprinkler irrigation and subsequently evaporating without entering the plant system is also part of evapotranspiration.

Evapotranspiration is mainly influenced by climatic factors such as net radiation, temperature, wind velocity and relative humidity. The volume of water transpired by plants depends in part on the water at their disposal, and also on temperature and humidity of air, wind movement, intensity and duration of sunshine.

There are two requirements for evaporation which can be stated as being clearly necessary: (1) There must be source of energy or heat and (2) Diffusion or flow of water vapor away from the surface must be maintained by some mechanism. In order to predict evapotranspiration, we can use the theory of balancing of energy at the earth surface alone by measuring all other significant terms, or we can predict evapotranspiration from the use of strictly diffusion or aerodynamic equations. We must realize, however, that (1) and (2) above must be met and that they are dependent upon each other.

The purpose of this research is to relate magnitude and variation of evapotranspiration to one or more climatic factors. For this, measured evapotranspiration data from a grass cover area was used, assuming that evapotranspiration of grass occurs largely in response to climatic conditions. A reference value, ETo, was introduce and defined as "the rate of evapotranspiration from an extended surface of 8 to 15 cm. tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water. "Four prediction formulae are presented to calculate ETo, adaptation of Blaney-Criddle, the Radiation, the Penman and the Pan Evaporation method. ETo was computed on monthly basis using the mean climatic data for the period considered and expressed in mm per day represents the mean value over that period.

The Blaney-Criddle equation (1950) is one of the most widely use methods to extimate crop water requirements. An adaptation of this method is suggested to calculate the reference crop evapotranspiration, ETo, when only measured air temperature data are available. The adaptation of Blaney Criddle equation have included other climatic factors, for example relative humidity and wind speed.

The Radiation method is used where available climatic data include measured air temperature and sunshine or cloudiness or radiation, but not wind and humidity. For this location, wind and humidity are also available. Relationships were developed between the radiation term and reference crop evapotranspiration, ETo, taking into account humidity and wind conditions.

The Penman equation consists of two terms, namely the energy (radiation) term and aerodynamic (wind and humidity) term. The relative importance of these two terms varies with climatic conditions. Under calm weather condition the aerodynamic term is usually much smaller than the energy term and vice versa.

The Pan Evaporation is the measurement of the intergrated effect of radiation, wind speed, temperature and relative hunidity on evaporation from an open water surface. In a similar fashion the plant respond to the same climatic variables but several major factors may produce significant differences in loss of water.

LOCATION

All climatic parameters used in this research were obtained from Mae-Jo Agricultural Meteorology Station. The station is located about 20 Kms north of Chiangmai, on latitude 18° 14' N and longgitude 99° 03'E the elevation is 316.644 meters above mean sea level. The data are measurement of these parameters on monthly basis during the year 1976:

1. Maximum, minimum and mean air temperature	°C
2. Dry-bulb and wet-bulb temperature	°C
3. Maximum, minimum and mean relative humidity	%
4. Wind speed at 11 meter height	m/sec
5. Actual possible bright sunshine hours	
6. Evaporation from class A pan	mm/day

OBJECTIVE

The objectives of this research is to determine evapotranspiration of reference crop by following methods :

1. Adaptation of Blaney-Criddle equation
2. Radiation method
3. Modified Penman equation and
4. Pan Evaporation method

Determine the correlation of the values calculated by these four methods, and suggest the best method for this area.

METHOD 1 BLANEY-CRIDDLE

Originally, Blaney-Criddle approach involves temperature, t and percentage of day time hours, p as climatic variables to predict the effect of climate on evapotranspiration. This is called the consumptive use factor f, where $f = p(0.46t + 8.13)$ when temperature is measured in degree Celcius (°C) and p is the percentage of annual daylight hours which occur during the period considered. The empirically crop coefficient (K) is then applied to establish the consumptive water requirement. Consumptive water requirement is defined as "the amount of water potentially required to meet the evapotranspiration needs of vegetative areas so that plant production is no limited from lack of water"

However, crop water requirements will vary widely between climates having similar air temperature; for example, between very dry and very humid climates, or between generally calm and very windy conditions. In order to define better the effect of climate on crop water requirements, Pruitt W.O. and Doorenbos J. (Rome 1975) had developed relationship between the Blaney-Criddle f factor and reference crop (grass) evapotranspiration ETo taking into account general values of relative humidity, sunshine hour and wind speed. The results are:

$$ETo = a + b[p(0.46 + 8.13)]$$

where ETo = reference crop (grass) evapotranspiration mm/day

t = mean air temperature

p = mean daily percentage of annual day time hour

a, b = variable parameters depend on the values of minimum relative humidity, wind speed at 2 m. height and daily sunshine hours.

METHOD 2 RADIATION METHOD

This method is suggested to predict the effect of climate on crop water requirements in areas where available climatic data include measured air temperature and sunshine or cloudiness or radiation, but not wind speed and relative humidity. Direct measurement of the duration of bright sunshine hours can be used to obtain a measurement of solar radiation. For areas where wind speed and relative humidity are also available, relationship between the radiation term and reference crop (grass) evapotranspiration, ETo, taking into account relative humidity and wind speed were developed by Pruitt W.O. and Doorenbos J. (Rome 1975). The result are:

$$ETo = a + b.\ WR_s$$

where ETo = reference crop (grass) evapotranspiration mm/day

R_s = solar radiation received at the earth surface mm/day

W = weighting factor which depends on temperature and altitude

a, b = variable parameters depend on the value of mean relative humidity and wind speed at 2 m. height

Solar radiation (R_s) is only a portion of the radiation received at the top of the atmosphere. The later is referred to as extra-terrestrial radiation (R_a). It is a function of latitude and time of the year only and hence can be calculated without reference to weather conditions. Values of R_a can be expressed in equivalent evaporation in mm/day which is a measure of the intensity of radiation; converted into heat, it can be related to the energy required to evaporate water from an open surface. Only a portion of the extra-terrestrial radiation received at the outer atmosphere penetrates to the earth's surface since a part is scattered and absorbed when passing through the atmosphere. The radiation received at the earth's surface is referred to here as solar radiation, R_s.

Solar radiation can be measured directly, but at this station such data can not be recorded. However, solar radiation can be adequately predicted from available bright sunshine duration records, as follows:-

$$R_s = (0.25 + 0.5\ {}^n/N)\ R_a$$

where n/N is the ratio between actual to maximum possible bright sunshine hours.

METHOD 3 MODIFIED PENMAN EQUATION

The original Penman (1948) equation predicted the loss of water by evaporation from an open water surface, and determined crop coefficients experimentally. The equation consists of two terms, namely the energy (radiation) term and aerodynamic (wind and humidity) term. The relative importance of the two terms varies with the climatic conditions. Under calm weather conditions the aerodynamic term is usually much smaller than the energy term.

An adaptation of Penman equation can be used for direct prediction of reference crop evapotranspiration by the use of appropriate reflection coefficients foe incoming solar radiation, the effect of plant resistance to transpiration and by inclusion of appropriate wind functions which taking into account the change in aerodynamic roughness with groeth of crop.

The formula presentented and procedure to follow will enable prediction of the effect of climate on reference crop evapotranspiration ETo. The calculationprocedures to estimate ETo may seem rather complicated. This is caused by the fact that the formula contains components which can be derived previously from recorded and related climate data when no direct measurements are not -- available.

$$ETo = 0.95 \left[W.R_n + (1-W).f(u).(e_a - e_d) \right]$$

where ETo	=	reference crop evapotranspiration	mm/day
W	=	temperature - related weighting factor	
R_n	=	net radiation	mm/day
f(u)	=	wind - related function	
$(e_a - e_d)$	=	the difference between the saturation vapor pressure at mean air temperature and the of the air	mbar

W is equal to $\frac{\Delta}{\Delta + \gamma}$ where Δ is rate of change of the saturation vapor pressure with temperature and γ is the psychrometric constant. (1 - W) is weighting factor for the effect of wind and humidity on ETo, it is related to temperature and elevation.

Net radiation (R_n), is the difference between all incoming and outgoing radiation, it can be measured or calculated. The calculations will be simplified and more reliable if solar radiation is known.

$$R_n = R_{ns} - R_{nl}$$

where R_{ns} = net shortwave radiation mm/day

R_{nl} = net longwave radiation mm/day

To calculate R_n the difference steps involved are :-

1. Obtain solar radiation from extra-terrestrial radiation R_a:

$$R_s = (0.25 + 0.50^{n} /N)\ R_a$$

2. Net shortwave radiation, R_{ns}, can be obtained by corrected R_s for reflectivity of the crop surface, α , which is usually equal to 0.25, then:

$$R_{ns} = (1 - \alpha)\ R_s$$

3. Net longwave radiation (R_{nl}) can be determined from available mean temperature, vapor pressure and n/N

$$R_{nl} = f(t).\ f(e_d).\ f(n/N)$$

where $f(t) = \sigma T^4$

$f(e_d) = 0.56 - 0.079\ e_d$ for humid climate

$f(n/N) = 0.1 + 0.9^{n}/N$

Wind function f(u) is a wind related function, the effect of wind on ETo using the modified Penman method has been define as:

$$f(u) = 0.27\left(1 + \frac{U_2}{100}\right)$$

where U_2 is total wind run in Km/day at 2 m. height

METHOD 4 PAN EVAPORATION

Evaporation pans provide a measurement of the integrated effect of radiation, wind speed, air temperature and relative humidity on evaporation from an open water surface. In a similar fashion the plant responds to the same climatic variables but several major factors may produce significant differences in loss of water. Also a great difference in water losses from pans and from crop covers can be caused by the variance in air turbulence just above the surfaces and in the temperature and humidity of the air immediately adjacent to these surfaces. The reference crop evapotranspiration ETo can be predicted by

$$ETo = K_p . E_{pan}$$

where ETo = reference crop evapotranspiration mm/day

K_p = pan coefficient

E_{pan} = pan evaporation mm/day

Value of K_p depend upon the relative humidity, wind speed, pan environment and type of pan.

Pan in this station is the class A evaporation pan. It is circular 121 cm. in diameter and 25.5 cm. deep. It is made of galvanize iron and mounted on a wooden open frame platform with its bottom 15 cm. above ground level.

DATA

Table 1 shows all data that needs in calculation which obtained from Mae-Jo Agricultural Meteorology station on monthly basis. The data include maximum, minimum and mean air temperature in degree Celcius, wetbulb and dry-bulb temperature also in degree Celcius. Humidity is recorded as maximum, minimum and mean relative humidity in percent. Wind speed is measured at 11 meter height, but it was converted to the speed at 2 meter height. Evaporation from class A pan is measured in millimeter and also actual possible bright sunshine hours are recorded.

Table 2 shows all constant data at specific location. These data are taken from Irrigation and Drainage Paper No 24 "Crop Water Requirement" by J. Doorenbos and W.O. Pruitt (FAO, UN, Rome 1975) the data obtained are:

1. Mean daily percentage (p) of annual day time hours at $20^{o}N$
2. Mean daily maximum duration of bright sunshine hours (N) at $20^{o}N$
3. Extra-terrestrial radiation (R_a) expressed in equivalent evaporation in mm/day

CALCULATION

METHOD 1 BLANEY-CRIDDLE

The equation that use to predict the evapotranspiration of reference crop are:

$$ETo = a + b\left[p(0.46t + 8.13)\right]$$

a and b are variable parameters depend on the value of minimum relative humidity, wind speed and ratio of actual to maximum possible bright sunshine hour, p is mean daily percentage of annual daytime hours and t is mean air temperature in degree Celcius.

Example

Month June 1976 Place Chiangmai Thailand

Data

t_{mean}		=	27.6 °C
lat. 19°N	p	=	0.30
RH_{min}		=	48 %
n/N		=	0.42
U_2		=	1.50 m/sec

From Fig. 1 page 14 Irrigation and Drainage Paper No 24 (FAO 1975) the values of a and b can be determine and

$$a = -2.00 \quad , \quad b = 1.05$$

$$\begin{aligned} \text{Then ETo} &= -2.00 + 1.05 \left[0.30(0.46 \times 27.6 + 8.13) \right] \\ &= -2.00 + 6.60 \\ &= 4.60 \quad \text{mm/day} \end{aligned}$$

Calculated ETo by this method for each month are shown in table 3 and design as ETo_1

METHOD 2 RADIATION METHOD

The relationship suggested to calculate reference crop evapotranspiration by this method is

$$ETo = a + b\, W.R_s$$

a and b are coefficient depend on mean relative humidity and wind speed but usually a has a constant value of -0.3. W is weighting factor which depends on air temperature and altitude, in this case the value of W is taken from the altitude of 500 meter above mean sea level. R_s is solar radiation expressed in equivalent evaporation in mm.day. At this station the solar radiation is not recorded, but can be calculated by knowing the value of extra-terrestrial radiation as follow :

$$R_s = (0.25 + 0.50\, n/N)\, R_a$$

Example

Month June 1976 Place Chiangmai Thailand

Data

t_{mean} = 27.6 °C

RH_{mean} = 73 %

U_2 = 1.50 m/sec

R_a = 16.3 mm/day

n/N = 0.42

From Fig. 2 page 25 Irrigation and Drainage Paper No 24 (FAO 1975) the values of b can be determine by knowing RH_{mean} and wind speed, b = 0.69 and a = -0.3. By knowing mean air temperature = 27.6°C, the weighting factor W = 0.78

Calculate solar radiation in mm/day

$$R_s = (0.25 + 0.50\ ^n/N)\ R_a$$

$$= (0.25 + 0.50 \times 0.42) \times 16.3$$

$$= 7.50 \quad \text{mm/day}$$

The ETo can be determined

$$ETo = a + b.W.R_s$$

$$= -0.3 + 0.69 \times 0.78 \times 7.50$$

$$= 3.74 \quad \text{mm/day}$$

Calculated ETo by this method for each month are shown in table 4 and designated as ETo_2

METHOD 3 MODIFIED PENMAN EQUATION

The relationship suggested to calculate evapotranspiration of reference crop are as followed

$$ETo = 0.95\ [\ W.R_n + (1 - W).f(u).(e_a - e_d)]$$

In this equation 0.95 is number use to correct the value of ETo which calculated by Penman for day and night time wind and relative humidity in this area. As mentioned before, there are two terms, radiation and aerodynamic term in this equation, Calculation can be done by the following steps:-

1. Calculate the value of radiation term

R_n is net radiation express in equivalent evaporation in mm/day

$$R_n = R_{ns} - R_{nl}$$

$$R_{ns} = (1 - \quad) R_s$$

$$R_s = (0.25 + 0.50\ ^n/N)\ R_a$$

$$R_{nl} = f(t).f(e_d).\ f\ (^n/N)$$

R_{ns} is net shortwave radiation, R_{nl} is net longwave radiation, is reflectivity of crop surface which is equal to 0.25, f(t), $f(e_d)$ and $f(^n/N)$ is function of temperature, vapor pressure and bright sunshine hours respectively.

$$f(t) = \sigma T^4$$

$$f(e_d) = 0.56 - 0.079\ e_d \quad \text{for humid area}$$

$$f(^n/N) = 0.10 + 0.9^n/N$$

σ is Boltzman constant which is equal to 2.01 X 10^{-9} in equivalent evaporation in mm/day and T is mean air temperature in degree Kelvin.

2. Calculate the value of aerodynamic term

Wind function f(u) can be determined by

$$f(u) = 0.27\ (1 + \frac{U_2}{100})$$

where U_2 is wind speed in Kms/day measured at 2 meter height, $(e_a - e_d)$ is difference between the saturation vapor pressure at mean air temperature and the mean actual vapor pressure of air both in mbars.

Example

Month June 1976 Place Chiangmai Thailand

Data

t_{mean} = 27.6 °C

R_a = 16.3 mm/day

$^n/N$ = 0.42

t_d = 28.6 °C

t_w = 24.8 °C

W = 0.78

Calculate the value of radiation term

$R_s = (0.25 + 0.50\ ^n/N)\ R_a$

$= (0.25 + 0.50 \times 0.42) \times 16.3$

$= 7.50$ mm/day

$R_{ns} = (1 - \ )\ R_s$

$= (1 - 0.25) \times 7.50$

$= 5.63$ mm/day

If $t_d = 28.6\ ^oC$ and $t_w = 24.8\ ^oC$, $e_d = 28.8$ mbars

$f(t) = 16.2$

$f(e_d) = 0.14$

$f(^n/N = 0.48$

$R_{nl} = f(t).f(e_d).f(^n/N)$

$= 16.2 \times 0.14 \times 0.48$

$= 1.09$ mm/day

$R_n = R_{ns} - R_{nl}$

$= 5.63 - 1.09$

$= 4.54$ mm/day

$WR_n = 0.78 \times 4.54$

$= 3.54$ mm/day

The calculated values of WR_n on monthly basis are shown in table 5. Aerodynamic term can be calculated as follow:-

t_{mean} = 27.6 °C e_a = 36.9 mbars

$e_a - e_d$ = 36.9 - 28.8 = 8.1 mbars

U_2 = 129.6 Kms/day f(u) = 0.62

and (1 - W) = (1 - 0.78) = 0.22

The calculated values of $(e_a - e_d)$, f(u) and (1 - W) on monthly basis are shown in table 6.

Table 7 shows the values of radiation terms, aerodynamic terms and evapotranspiration of reference crop (ETo) which calculated by Modified Penman equation. The value of ETo in table 7 are designated as ETo_3

METHOD 4 PAN EVAPORATUON

The value of evapotranspiration of reference crop can be determined from pan evaporation by this relationship:

$$ETo = K_p . E_{pan}$$

E_{pan} is depth of water evaporated from class A pan in mm/day. K_p is pan coefficient depend upon the relative humidity and wind speed, pan environment and type of pan.

Example

Month June 1976 Place Chiangmai Thailand

Data

E_{pan} = 5.1 mm/day

RH_{mean} = 73 %

Wind speed = 175 Kms/day (light)

Upwind distance of green crop 10 m.

K = 0.85

ETo = 0.85 X 5.1

= 4.8 mm/day

Table 8 show values of all data and evapotranspiration of reference crop calculated by this mehod. The value of ETo is designated as ETo_4

DISCUSSION

The four methods that used to calculate the reference crop evapotranspiration are based on different assumptions. The first method, Blaney-Criddle, by usage, has proven to be the most universally acceptable formula for estimating consumptive use. The adaptation of Blaney-Criddle equation had taken into account the value of realtive humidity, sunshine hour and wind speed, that make the results more reliable.

It is very simple, instead of using the radiation and aerodynamic terms directly, the temperature, sunshine hours and variable parameters a and b are used in this equation.

Radiation method is concentrated on the effect of radiation on reference crop evapotranspiration. Aerodynamic factors are also taking into account but considered as minor factors. Weighting factor W is an important parameter which distinguish the effect of radiation and aerodynamic terms on evapotranspiration.

The third one, Penman equation which modified to be used for direct prediction of reference crop evapotranspiration. The equation consists of two terms, named radiation (WR_n) and aerodynamic $(1-W)f(u)(e_a - e_d)$ terms. The weighting factor W is temperature-related weighting factor, it depends absolutely on mean air temperature and altitude. It indicates the effect of radiation and aerodynamic terms on evapotranspiration in this equation by factor W and (1-W). From the plot of W and mean air temperature in degree celcius at elevation 500 meters above mean sea level (Fig. 2), shows that at mean air temperature of 6°C (42.8 °F) the value of W is equal to 0.5, thus at this temperature the effect of both radiation and aerodynamic terms on evapotranspiration are the same.

The value measured from pan evaporation is assumed that all climatic factors are influenced on rate of evaporation. It is the exact value that evaporation from water surface has occurred, only K_p which varies as the type of pan, relative humidity and wind speed shows the relationship between evaporation and reference crop evapotranspiration.

As shown in Fig. 3 the value calculated by Blaney-Criddle method is higher than that measured from pan. Radiation method gives values somewhat higher than that measured from pan except in rainy season from May through September. Modified Penman equation gives the -- results very closed to that measured from pan. The ratio of ETo_3 to ETo_4 is ranged rom 0.84 - 1.09, while the ratio of ETo_1 and ETo_2 to ETo_4 are ranged from 0.76 - 1.38 and 0.76 - 1.48 respectively. As shown in Fig. 4.

CONCLUSION

All three methods that used to calculate the values of reference crop evapotranspiration is slightly higher than evaporation measured by class A open pan. The Penman equation has been proved that the value calculated from this equation is very closed to evaporation value. It has been tasted extensively in many parts of the world with generally good results. And now, in this area, this location and this type of climate it also proved again that, it is better than other two methods. The statistical analysis is also supported this conclusion.

It must be realized that all climatic factors have some influenced on evapotranspiration, even one factor can not be neglected. These results are calculated from data taken at Mae-Jo Agricultural Meteorology station for only one year and calculated on monthly basis. For better results the calculation should done based on daily basis or shorter period for some years. The location of this station is very good, the results can be use in agricultural works in surrounded area.

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Table 1 Climatic data from Mae-Jo Agricultural Meteorology station

Month	Air Temp.			t_w	t_d	Relative Humidity			U_{11}	U_2	n	E_{pan}
	t_{max}	t_{min}	t_{mean}			RH_{max}	RH_{min}	RH_{mean}				
Jan	27.6	11.3	19.5	17.2	21.3	100	31	66	1	0.75	8.8	3.2
Feb	31.0	13.1	22.1	18.4	24.2	99	25	63	1	0.75	9.5	4.6
Mar	33.8	17.4	25.6	20.9	27.8	98	29	64	1	0.75	8.0	5.1
Apr	35.1	21.5	28.3	23.7	30.3	96	33	65	2	1.50	8.1	6.5
May	32.3	22.9	27.6	24.6	27.2	98	48	73	2	1.50	6.0	5.5
Jun	32.3	22.8	27.6	24.8	28.6	97	48	73	2	1.50	5.6	5.1
Jul	32.3	23.5	27.9	24.8	28.3	97	49	73	2	1.50	3.6	4.7
Aug	30.3	22.9	26.6	24.4	26.8	99	56	78	2	1.50	3.0	4.2
Sep	31.0	22.9	27.0	24.9	27.5	99	53	76	1	1.50	5.7	4.8
Oct	30.8	21.8	26.3	24.2	26.9	100	50	75	1	1.50	6.7	4.0
Nov	29.0	19.3	24.2	21.9	25.1	99	47	73	1	1.50	4.4	3.6
Dec	28.6	14.3	21.4	19.3	23.1	99	36	68	1	1.50	7.1	3.1

Table 2 Constant parameters at 19°N and 500 meters above mean sea level

Month	p	N	R_a
Jan	0.25	11.0	11.4
Feb	0.26	11.5	12.9
Mar	0.27	12.0	14.9
Apr	0.28	12.6	15.6
May	0.29	13.1	16.2
Jun	0.30	13.3	16.3
Jul	0.30	13.2	16.2
Aug	0.29	12.8	15.9
Sep	0.28	12.3	14.9
Oct	0.26	11.7	13.5
Nov	0.25	11.2	11.8
Dec	0.25	10.9	10.9

Table 3 ETo_1 Calculated by Blaney-Criddle method

Month	t_{mean}	n	RH_{mean}	U_2	p	N	n/N	a	b	ETo_1
Jan	19.5	8.8	31	0.75	0.25	11.0	0.80	-2.20	1.20	2.93
Feb	22.1	9.5	25	0.75	0.26	11.5	0.83	-2.40	1.37	4.12
Mar	25.6	8.0	29	0.75	0.27	12.0	0.67	-2.20	1.20	4.25
Apr	28.3	8.1	33	1.50	0.28	12.6	0.64	-2.20	1.20	4.91
May	27.6	6.0	48	1.50	0.29	13.1	0.46	-2.00	1.05	4.34
Jun	27.6	5.6	48	1.50	0.30	13.3	0.42	-2.00	1.05	4.56
Jul	27.9	3.6	49	1.50	0.30	13.2	0.27	-2.00	1.05	4.60
Aug	26.6	3.0	56	1.50	0.29	12.8	0.23	-1.45	0.80	3.27
Sep	27.0	5.7	53	0.75	0.28	12.3	0.46	-1.45	0.80	3.15
Oct	26.3	6.7	50	0.75	0.26	11.7	0.57	-2.00	1.05	3,52
Nov	24.2	4.4	47	0.75	0.25	11.2	0.39	-2.00	1.05	3.06
Dec	21.4	7.1	36	0.75	0.25	10.9	0.65	-2.20	1.20	3.19

Table 4 ETo_2 Calculated by Radiation method

Month	t_{mean}	n	RH_{mean}	U_2	N	R_a	W	n/N	R_s	b	ETo_2
Jan	19.5	8.8	66	0.75	11.0	11.4	0.70	0.80	7.41	0.76	3.50
Feb	22.1	9.5	63	0.75	11.5	12.9	0.72	0.83	8.58	0.76	4.39
Mar	25.6	8.0	64	0.75	12.0	14.5	0.76	0.67	8.48	0.76	4.60
Apr	28.3	8.1	65	1.50	12.6	15.6	0.78	0.64	8.89	0.76	4.97
May	27.6	6.0	73	1.50	13.1	16.2	0.78	0.46	7.78	0.69	3.89
Jun	27.6	5.6	73	1.50	13.3	16.3	0.78	0.42	7.50	0.69	3.74
Jul	27.9	3.6	73	1.50	13.2	16.2	0.78	0.27	6.24	0.69	3.06
Aug	26.6	3.0	78	1.50	12.8	15.9	0.76	0.23	5.80	0.69	2.74
Sep	27.0	5.7	76	0.75	12.3	14.9	0.78	0.46	7.15	0.69	3.55
Oct	26.3	6.7	75	0.75	11.7	13.5	0.76	0.57	7.22	0.69	3.49
Nov	24.2	4.4	73	0.75	11.2	11.8	0.74	0.39	5.25	0.67	2.38
Dec	21.4	7.1	68	0.75	10.9	10.9	0.72	0.65	6.27	0.76	3.13

Table 5 Determination the value of Net radiation for Penman equation

Month	t_{mean}	t_w	t_d	R_a	W	e_d	$^n/N$	R_s	R_{ns}	f(t)	$f(e_d)$	$f(^n/N)$	R_{nl}	R_n	WR_n
Jan	19.5	17.2	21.3	11.4	0.70	16.6	0.80	7.41	5.56	14.5	0.24	0.82	2.85	2.71	1.90
Feb	22.1	18.4	24.2	12.9	0.72	16.8	0.83	8.58	6.44	15.0	0.24	0.85	3.06	3.38	2.43
Mar	25.6	20.9	27.8	14.5	0.76	20.2	0.67	8.48	6.36	15.7	0.21	0.71	2.34	4.02	3.06
Apr	28.3	23.7	30.3	15.6	0.78	24.4	0.64	8.89	6.67	16.3	0.17	0.68	1.88	4.79	3.74
May	27.6	24.6	27.2	16.2	0.78	28.9	0.46	7.78	5,84	16.2	0.14	0.52	1.19	4.65	3.63
Jun	27.6	24.8	28.6	16.3	0.78	28.8	0.42	7.50	5.63	16.2	0.14	0.48	1.09	4.54	3.54
Jul	27.9	24.8	28.3	16.2	0.78	28.5	0.27	6.24	4.68	16.3	0.14	0.35	0.80	3.88	3.03
Aug	26.6	24.4	26.8	15.9	0.77	29.0	0.23	5.80	4.35	16.0	0.14	0.31	0.69	3.66	2.82
Sep	27.0	24.9	27.5	14.9	0.77	29.9	0.46	7.15	5.36	16.1	0.13	0.52	1.09	4.27	3.29
Oct	26.3	24.2	26.9.	13.5	0.76	28.5	0.57	7.22	5.42	16.0	0.14	0.64	1.43	3.99	3.03
Nov	24.2	21.9	25.1	11.8	0.74	24.2	0.39	5.25	3.94	15.4	0.17	0.45	1.18	2.76	2.04
Dec	21.4	19.3	23.1	10.9	0.71	19.9	0.65	6.27	4.70	14.8	0.21	0.73	2.27	2.43	1.72

Table 6 Determination the value of Aerodynamic term

Month	T_{mean}	t_w	t_d	U_2	(1-W)	e_a	e_d	$(e_a - e_d)$	f(u)
Jan	19.5	17.2	21.3	67.4	0.30	22.7	16.8	5.9	0.45
Feb	22.1	18.4	24.2	67.4	0.28	26.6	16.6	10.0	0.45
Mar	25.6	20.9	27.8	67.4	0.24	32.8	20.2	12.6	0.45
Apr	28.3	23.7	30.3	129.6	0.22	38.5	24.4	14.1	0.62
May	27.6	24.6	27.2	129.6	0.22	36.9	28.9	8.0	0.62
Jun	27.6	24.8	28.6	129.6	0.22	36.9	28.8	8.1	0.62
Jul	27.9	24.8	28.3	129.6	0.22	37.6	28.5	9.1	0.62
Aug	26.6	24.4	26.8	129.6	0.23	34.9	29.0	5.9	0.62
Sep	27.0	24.9	27.5	67.4	0.23	35.7	29.9	5.8	0.45
Oct	26.3	24.2	26.9	67.4	0.24	34.2	28.5	5.7	0.45
Nov	24.2	21.9	25.1	67.4	0.24	30.2	24.2	6.0	0.45
Dec	21.4	19.3	23.1	67.4	0.29	25.5	19.9	5.6	0.45

Table 7 ETo_3 Calculated by Modified Penman equation

Month	WR_n	1-W	f(u)	$(e_a - e_d)$	Aero term	ETo_3
Jan	1.90	0.30	0.45	5.9	0.80	2.57
Feb	2.43	0.28	0.45	10.0	1.26	3.51
Mar	3.06	0.24	0.45	12.6	1.36	4.20
Apr	3.74	0.22	0.62	14.1	1.92	5.38
May	3.63	0.22	0.62	8.0	1.09	4.48
Jun	3.54	0.22	0.62	8.1	1.10	4.41
Jul	3.03	0.22	0.62	9.1	1.20	4.06
Aug	2.82	0.23	0.62	5.9	0.84	3.48
Sep	3.29	0.23	0.45	5.8	0.60	3.70
Oct	3.03	0.24	0.45	5.7	0.62	3.47
Nov	2.04	0.26	0.45	6.0	0.70	2.60
Dec	1.72	0.29	0.45	5.6	0.73	2.33

Table 8 ETo_4 Calculated by Pan evaporation

Month	U_2	RH_{mean}	K_p	E_{pan}	ETo_4
Jan	67.4	66	0.75	3.2	2.4
Feb	67.4	63	0.75	4.6	3.5
Mar	67.4	64	0.75	5.1	3.8
Apr	129.6	65	0.75	6.5	4.9
May	129.6	73	0.85	5.5	4.7
Jun	129.6	73	0.85	5.1	4.3
Jul	129.6	73	0.85	4.7	4.0
Aug	129.6	78	0.85	4.2	3.6
Sep	67.4	76	0.85	4.8	4.1
Oct	67.4	75	0.85	4.0	3.4
Nov	67.4	73	0.85	3.6	3.1
Dec	67.4	68	0.75	3.1	2.3

Table 9 Ratio of ETo_1, ETo_2, ETo_3 to ETo_4

Month	ETo_1/ETo_4	ETo_2/ETo_4	ETo_3/ETo_4
Jan	1.22	1.46	1.07
Feb	1.18	1.25	1.00
Mar	1.12	1.21	1.10
Apr	1.00	1.01	1.09
May	0.92	0.83	0.95
Jun	1.06	0.87	1.02
Jul	1.15	0.77	1.01
Aug	0.90	0.76	0.97
Sep	0.76	0.87	0.90
Oct	1.03	1.02	1.02
Nov	0.99	0.77	0.84
Dec	1.38	1.36	1.01

Table 10 Comparison between ETo_1 and ETo_4

ETo_1	ETo_4	Di	di	di^2
2.93	2.4	0.53	0.38	0.1444
4.12	3.5	0.62	0.47	0.2209
4.25	3.8	0.45	0.30	0.0900
4.91	4.9	0.01	-0.14	0.0196
4.34	4.7	-0.36	-0.51	0.2601
4.56	4.3	0.26	0.11	0.0121
4.60	4.0	0.60	0.45	0.2025
3.27	3.6	-0.33	-0.48	0.2304
3.15	4.1	-0.95	-1.10	1.2100
3.52	3.4	0.12	-0.03	0.0009
3.06	3.1	-0.04	-0.19	0.0361
3.19	2.3	0.89	0.74	0.5476

Di = 1.8 $\qquad$ di^2 = 2.9746

$\bar{D}$ = 0.15 $\qquad$ S^2_D = 0.2704

$S^2_{\bar{D}}$ = 0.0225

$S_{\bar{D}}$ = 0.1501

t = 0.9992

From table t 0.90 = 1.36

t 0.80 = 0.876

ETo_1 and ETo_4 are difference at a level of significance of 0.20

Table 11 Comparison between ETo_2 and ETo_4

ETo_2	ETo_4	Di	di	di^2
3.50	2.4	1.10	1.155	1.334025
4.39	3.5	0.89	0.945	0.893025
4.60	3.8	0.80	0.855	0.731025
4.97	4.9	0.07	0.125	0.015625
3.89	4.7	-0.81	-0.755	0.570025
3.74	4.3	-0.56	-0.505	0.255025
3.06	4.0	-0.94	-0.885	0.783225
2.74	3.6	-0.86	-0.805	0.648025
3.55	4.1	-0.55	-0.495	0.245025
3.49	3.4	0.09	0.145	0.021025
2.38	3.1	-0.72	-0.665	0.442225
3.13	2.3	0.83	0.885	0.783225
		Di = -0.66		di^2 = 6.7215
		$\overline{D}$ = -0.055		S^2_D = 0.6110

S^2_D = 0.0509

$S_{\overline{D}}$ = 0.2256

t = 0.24

From table t 0.60 = 0.260

t 0.55 = 0.129

ETo_2 and ETo_4 are difference at a level of significance of 0.45

Table 12 Comparison between ETo_3 and ETo_4

ETo_3	ETo_4	Di	di	d_i^2
2.57	2.4	0.17	0.1625	0.0264062
3.51	3.5	0.01	0.0025	0.00001375
4.20	3.8	0.40	0.3925	0.1540562
5.38	4.9	0.48	0.4725	0.2232562
4.48	4.7	-0.22	-0.2275	0.0517562
4.41	4.3	0.11	0.1025	0.0105062
4.06	4.0	0.06	0.0525	0.00275625
3.48	3.6	-0.12	-0.1275	0.0162562
3.70	4.1	-0.40	-0.4075	0.1660562
3.47	3.4	0.07	0.625	0.390625
2.60	3.1	-0.50	-0.5075	0.2575562
2.33	2.3	0.03	0.0225	0.00050625

Di = 0.09 $\quad d_i^2$ = 1.2997433

$\overline{D}$ = 0.0075 $\quad S_D^2$ = 0.1181584

$S_{\overline{D}}^2$ = 0.0098

$S_{\overline{D}}$ = 0.0992

t = 0.076

ETo_3 and ETo_4 are non significance

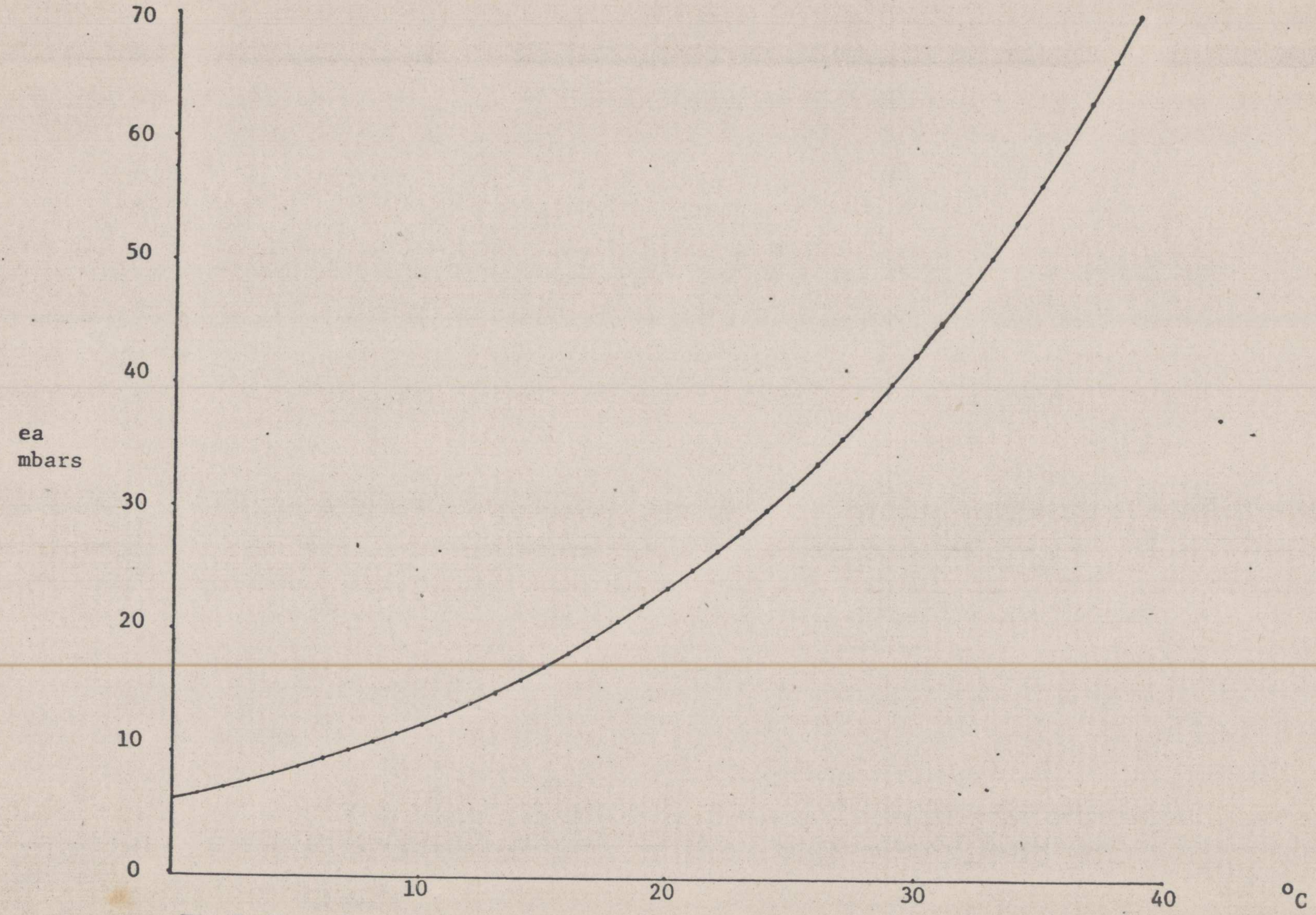

Fig I Plot of ea vs mean air temperature (Drawn from table 7 P.39 Irrigation and Drainage Paper NO.24 "Crop Water Requirement", Rome 1975)

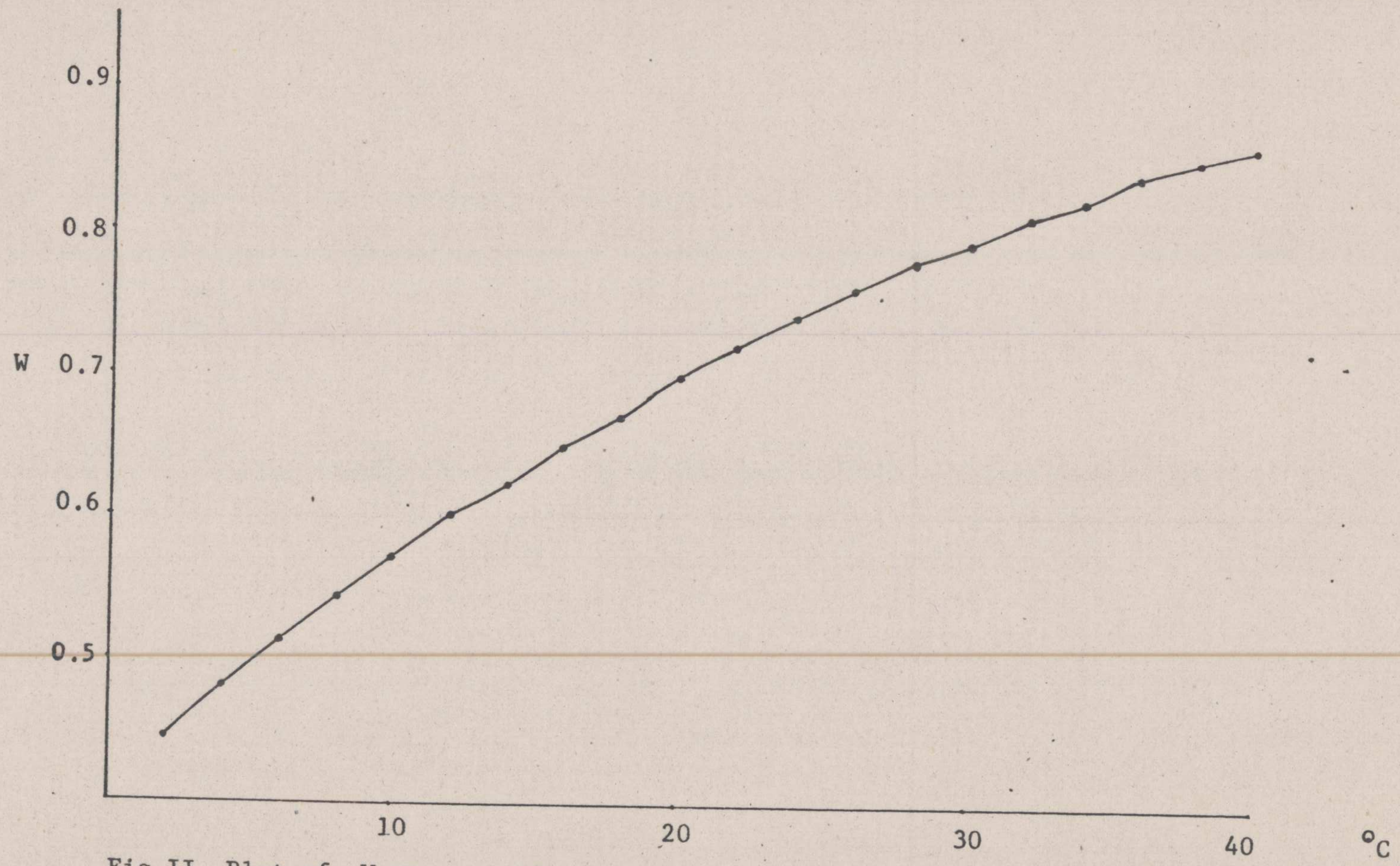

Fig II Plot of W vs mean air temperature (Drawn from table 11 P.43 Irrigation and Drainage Paper NO.24 "Crop Water Requirement", FAO, Rome, 1975) (Altitude 500 m.)

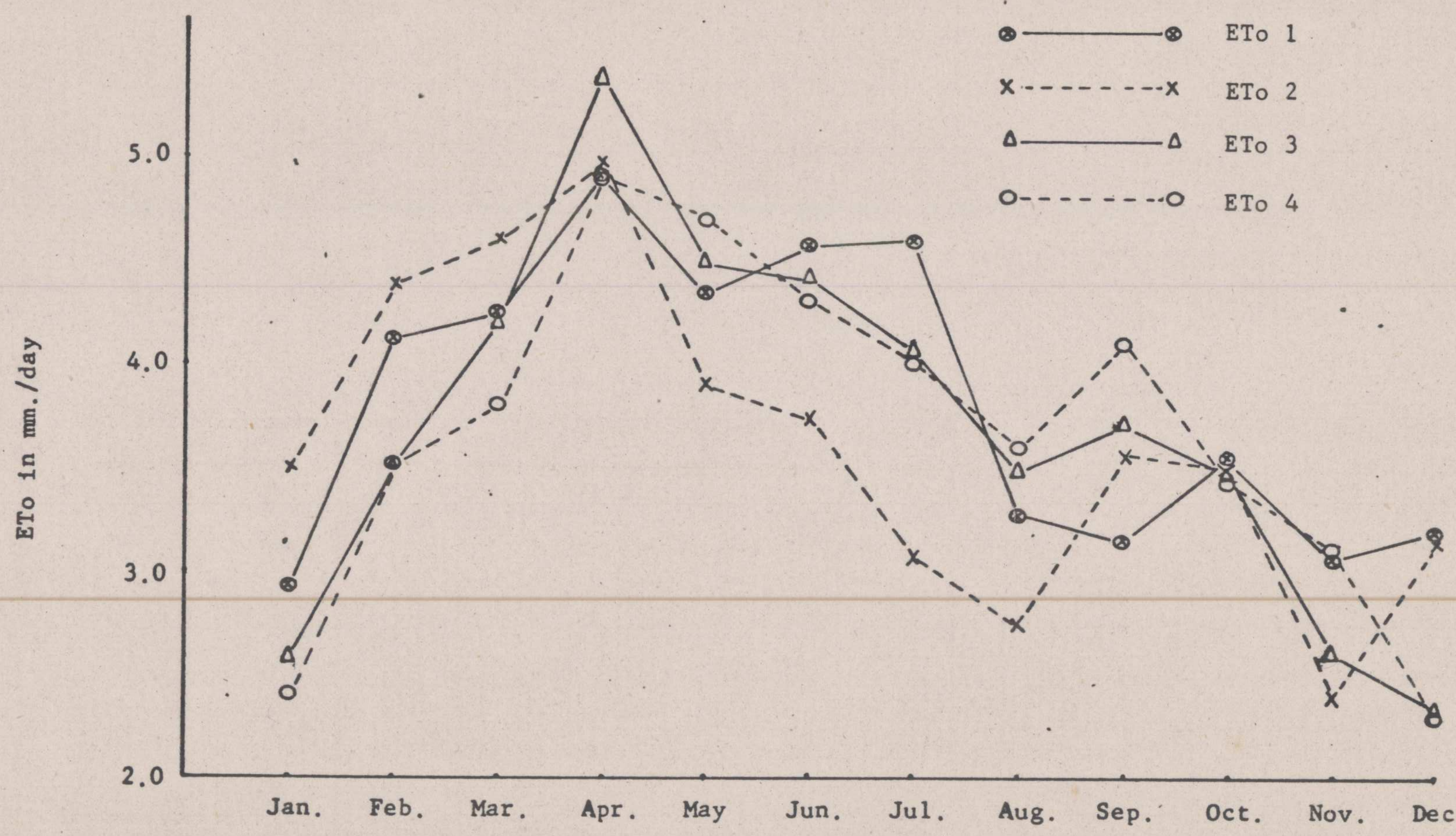

Fig. III. Plot of ETo VS Time

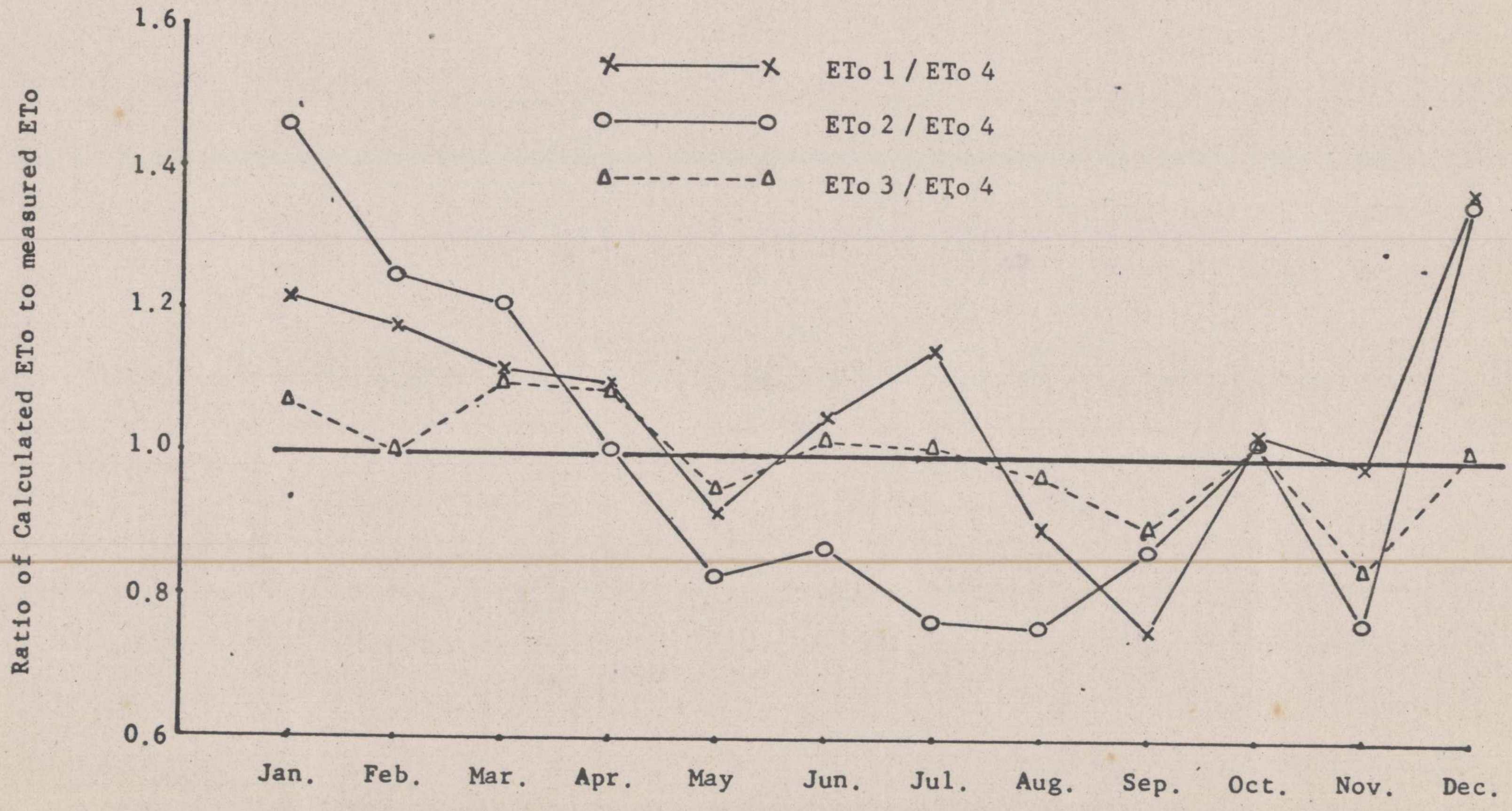

Fig. IV. Plot of Ratio of Caculated ETo to measured ETo vs Time.