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DETERMINATION OF ACTUAL WATER CONSUMPTION AND CROP COEFFICIENT OF MATURE BANANA IN CENTRAL JORDAN VALLEY.

BY
NAEM TH. MAZAHREH

عميد كلية الدراسات العليا

ADVISOR
Dr. IBRAHIM GHAWI

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This thesis was defended successfully on May,26,1993.

COMMITTEE MEMBERS		SIGNATURE
1.	Dr. Ibrahim Ghawi Associate Professor of Soil physics	
2.	Dr. Anwar Battikhi Professor of Soil Physics	
3.	Dr. Muhammad Shatanawi Associate Professor of Irrigation	
4.	Dr. Mostafa Qrunfleh Associate Professor of Horticulture	
5.	Dr. Ahmad Abu Awwad Assistant Professor of Irrigation	

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ABSTRACT

A research was carried out during 1991 growing season at the University of Jordan Experimental Station in the Jordan Valley. The objectives of the study were; (1) to determine the actual water consumption of mature banana (Musa spps. (Cavendish) cv. Paz.); and (2) to determine its crop coefficient values (Kc) using lysimeter with bermuda grass as a reference crop, class-A pan evaporation (Epan), and six selected indirect methods.

Actual evapotranspiration (ETa) of mature banana was measured by depletion method using neutron scattering techniques. The effect of 50, 100, and 150% of weekly class-A pan evaporation replenishment (Epan) under basin irrigation were investigated using randomized complete block design with four replications. Area of each basin was 81 m^2 which encompassed nine banana trees. The total water applied were 1064, 1739, and 2413 mm for 50, 100, and 150% of Epan, respectively.

Results indicated that ETa of mature banana for 50, 100, and 150% of Epan were 941, 1152, and 1310 mm, respectively. Increasing amounts of water applied resulted in a significant increase in pseudostem height, girth, and bunch weight. Yield and water use efficiency (WUE) of bananas irrigated at 100% of Epan were 33.11 ton/ha and 2.87 kg/m^3, respectively. Reducing the irrigation level to 50% of Epan reduced the yield by 89.52% and WUE by 87.77%. Increasing irrigation

level to 150% of Epan gave no significant effect on yield which increased only by 12%, and on WUE which was reduced by 1.7%.

Class-A pan evaporation (Epan) was highly correlated with Actual water consumption of mature bananas (ETa) and potential evapotranspiration for grass (ETPlys) with R^2 values of 0.93 and 0.86, respectively, followed by ETPB-C. The mean maximum temperature was found to be the most significant climatic factor in predicting ETa, ETPlys, and Epan.

1.0 INTRODUCTION

Water is an essential natural resource with multiple uses. The importance of water increases in arid and semi-arid regions because of scarcity. Water limitation is considered as the greatest challenge facing agricultural development in these regions like Jordan. It is expected that by the year 2000, water demand will rise to about 1100 million cubic meters (MCM). Of which about 800 MCM will be utilized for agricultural purposes and 300 MCM for domestic and industrial purposes (Nasser, 1986).

However, as water becomes increasingly scarce and more expensive developing, precise information for efficient water management is needed. Accordingly, the actual amount of water required by crops becomes the most important factor for judicious application of irrigation water, design of irrigation systems, and for judging of the adequacy of water supplies. All of their segments contribute in increasing water use efficiency and optimizing crop production.

Banana is considered as one of the most important crops in its nutritious and economical values. Total area planted with banana in the Jordan Valley is 11,886 du. (General Statistics Department, 1990). It is considered as the highest water consuming crop with a rapid growth rate. Banana, as a herbaceous mesophytic plant, is more sensitive to moisture stress than other fruit crops. Accurate information

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2. LITERATURE REVIEW

Water is a vital element to all living organisms. Although it occupies about two-thirds of the universe, good water is really scarce in arid and semi arid regions such as in Jordan.

Good water management is essential for obtaining optimum yield, provided other management practices are also optimum. Water requirements must be determined for the local environment if it is to be meaningful (Hegde and Srinivas, 1988).

Van Bavel et al. (1961) defined evapotranspiration (ET) as the process of water movement from the earths land surface to the atmosphere in vapor form. Thus it includes evaporation from the surface of the soil and plant, as well as transpiration of water by leaves and the net flow of water vapor across the liquid-air interface in the free pore space of the soil. The term evapotranspiration quantitatively defines the amount of water (expressed as equivalent bonded depth) lost from the earth's surface over some period of time.

Different estimates of annual ET of banana were reported in different parts of the world. For example, Simmonds (1966) and Bovee (1975) estimated annual banana ET in Lebanon as 1200 mm. In India, it was 1560 mm as reported by Bhattacharya and Rao (1985). In the Sula Valley, in Handuras, Ghavami (1973) a value of 2184 mm was reported.

Young and Summis (1985) estimated banana ET as 2690 mm in Hawaii Agricultural Experiment Station in U.S.A. These large differences in ET values are apparently due to prevailing climatic conditions, irrigation interval and methods of ET measurement.

Water is the most important factor affecting banana growth and yield. Shmueli (1953) reported that moderate moisture deficiency led to a decrease in plant turgidity, closure of stomata, growth retardation, and a decline in fruit production. He concluded that under Jordan Valley conditions, the range between field capacity and two-thirds of total available water constituted the optimum range of soil moisture for Cavendish banana, with regard to physiological activity and yield.

Trochoulais (1973) studied the yield responses of bananas grown under a series of irrigation regimes over a three-year period (1968-1970) in New South Wales. The results showed that bunch numbers, fruit weight, and hand and finger length increased significantly with decreased moisture deficit. He also reported that application of 7.7 mm of water every three to five days during dry periods produced about double the yield of non-irrigated treatment.

Krishnan and Shanmugavelu (1980) studied water requirements of banana CV. Robusta irrigated at 20, 40, and 60 percent of available moisture in Coimbatore of Tamil Nadu. They found that the total water consumption ranged from 1981 to 2150 mm for the various treatments, and considered irrigation when the range of soil moisture between 60 and 80 % of available soil moisture to be optimal for bananas production.

Ghavami (1973) estimated water requirements of Valery bananas using drainage lysimeters in Honduras. He reported a value of 2184 mm as the seasonal actual ET, and the optimum growth occurred in a well-drained aerated root zone with moisture continuously maintained near field capacity.

Holder and Gumbs (1982) in the Windward Island found that significant increase in fruit yield was obtained from treatments irrigated at 66 and 75 % of available soil moisture compared to 50% level.

According to Martinez (1986) in Havana (Cuba), best yield (43 t/ha) was obtained by maintaining soil moisture over 85% of available soil moisture. The lowest yield (9 t/ha) was obtained from the non irrigated treatment.

Young and summis (1985) in Hawaii reported that daily application of irrigation water using drip irrigation system which maintained soil moisture in the root zone near the field capacity doubled banana yields with ET of 2690 mm.

Manica et al.(1975) in French Antilles reported that hands and fruits per bunch and fruit yield per hectare of banana Cv. Nancao decreased linearly with decreasing soil moisture.

Lahav and Kalmar (1988) studied the effect of different amounts of applied water which ranged from 8450 to 14470 $m^3.ha^{-1}.year^{-1}$ on the yield and growth of bananas in the Jordan Valley. The results indicated that increasing water amounts led to an increase in sucker height, earlier flowering, and more bunches. Maximum effects were found in suckers irrigated with maximum amount of water; but any increase above 10370 $m^3.ha^{-1}.year^{-1}$ gave no significant effect. They also recorded that maximum ET of 7.4 mm/day occurred during June and July.

Hegde and Srinivas (1988) found that total ET for banana CV. Robusta in India were 1864, 1601, 1305, and 1046 mm for soil matric potentials of 25, 45, 65, and 85 KPa, respectively. They also reported maximum water use efficiency of 370 Kg/cm.ha with irrigation at 45 KPa.

Bhattacharya and Rao (1985) found that yield of bananas in India were 108.5, 82.0, and 40 ton/ha for 20, 40, and 60 % depletion of available soil moisture, respectively. While total consumptive use were 1560, 1480, and 1375 mm for 20, 40, and 60 % depletion of the available soil moisture, respectively. Water use efficiencies were 695, 553, and 290 Kg/cm.ha for these respective treatments. They also indicated that manipulation of the soil moisture regime through the use of soil covers would enhance banana productivity. By using 800 gauge black polyethylene film covers, the yields were 160.7, 123.2 and 54.8 ton/ha and the water consumptions were 1057, 1044 and 1024 mm for 20, 40, and 60 % depletion of the

September).

Methods that predict crop water consumption using of climatic variables are used frequently for irrigation scheduling because accurate field measurements are difficult to obtain. These methods predict the water use of a standardized reference crop , which is defined as " the rate of evapotranspiration from an extensive surface of 80 to 150 mm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Doorenbos and Pruitt, 1977). Crop coefficients (Kc) are used to adjust this value for specific crop and climatic conditions. (Doorenbos and Pruitt, 1977).

Results obtained in Australia showed that class-A pan evaporation data can be used successfully to schedule trickle irrigation of bananas. It was found that irrigation equivalent to 60 % of class-A pan evaporation applied twice a week gave maximum yield and greatest efficiency of water use (Trochoulias and Murison, 1981).

Using Blaney-Criddle equation, Abu-Khayt (1978) reported that annual water requirement of bananas in Jordan were 2011.4, and 2605 mm in Al-Baqura and Ghor Al-safi, respectively. Whereas, using the same equation, Loucas and Phanartizis (1975) reported that ET in Cyprus was 1506 mm.

In spite of many objections to the use of pan evaporation as an estimate of ET, the correlation of ET to pan evaporation over weekly or monthly period is relatively

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3.0 MATERIALS AND METHODS

3-1 Study location :

The experiment was carried out during 1991 growing season at the University of Jordan Experimental Station located in the central region of the Jordan Valley, at a latitude of 32° N, 35°:30` East-longitude with elevation of 300 meter below the sea level.

3-2 Soil properties :

Soil samples down to 90 cm depth were collected from three locations representing the experimental area. Undisturbed soil samples were taken from 0-15, 15-30, 30-45, 45-60, 60-75, and 75-90 cm depths. Soil characteristic curve for each layer was prepared using the ceramic plate extractor method (Richard, 1965), at 0.1, 0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 7.0, 10, and 15 bars.

Textural class, apparent specific gravity, total nitrogen, available phosphorus, available Potassium, electrical conductivity (EC),and soil reaction (pH) were determined by pipette method (Day, 1965), core method (Black, 1965) Kjeldhal method (Bremner, 1965),Olsen method (Olsen , and Dean,1965), Ammonium acetate ($CH_3.COONH_4$) extraction method (Pratt, 1965), the conductivity bridge in 1:2.5 soil water extract(Bower and Wilcox, 1965), and pH-meter in 1:1 soil water suspensions, respectively.

3-3-1 Plant material.

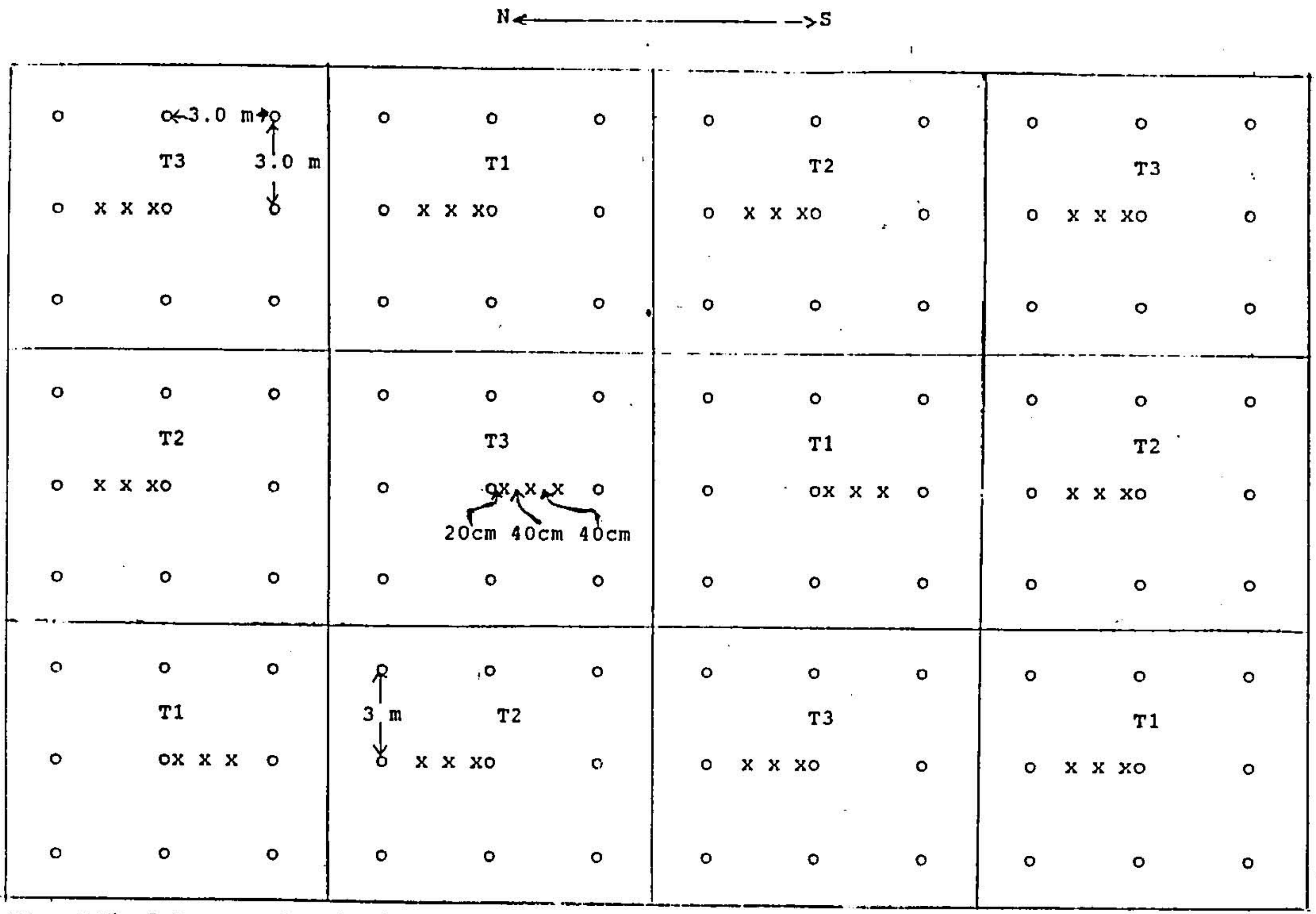
Madion suckers of banana Musa spp.(Cavendish) cv. Paz. were planted in April, 1988 at a spacing of 3.0 x 3.0 m. Three similar suckers in size were allowed to grow around each banana mother , all unwanted suckers were removed. The experiment was started in 1 January, 1991 when the suckers were about five months old.

3-3.2 Irrigation treatments.

The experiment was laid out in a completely randomized block design with four replications (Fig. 1). The irrigation treatments were 50(T1), 100(T2), and 150(T3) percent of weekly class-A pan evaporation. Each plot size was 9.0 x 9.0 m containing 9.0 mats. Each mat developed three banana suckers at various stages of growth. Each plot was leveled and surrounded by earth bunds. Three access tubes (standard 5.0 cm I.D. Galvanized tubing 1 m length) were installed in each plot at distances of 20, 60, and 100 cm from the central mat in the same direction. The plots were irrigated by flooding through PE pipe line (32 mm) diameter. The volume of water applied to each plot was measured by a flow meter placed at the end of the line.

3-4 Cultural practices.

All plots were fertilized with potassium sulfate (0:0:50) at a rate of 1029 Kg/ha, and urea (46:0:0) at a



T1 = 50% of Epan; T2 = 100% of Epan; T3 = 150% of Epan; o = banana tree; x = access tube.

Figure(1) Lay - out of the experiment at the University of Jordan Experimental Station in the Jordan Valley, 1991.

rate of 772 Kg/ha. Potassium sulfate was broadcasted once at the beginning of the experiment, whereas urea was applied twice each month. (Starting in January, 1991).

3-5 Measurements.

All plant measurements were carried out for the central three banana plants.

3-5-1. Yield

Bunches were harvested when they had reached commercial fullness. Bunch weight, number of hands, number of fingers for each bunch, flowering and harvesting date were recorded.

3-5-2. Pseudostem height and girth.

Plant height was measured from ground to the curve of bunch stalk. Pseudostem girth was measured at 90 cm above the ground after flowering.

3-6. Neutron probe calibration curves.

Calibration curves for moisture determination were constructed for each of the six depths. Soil moisture samples for gravimetric moisture measurement using 1 inch diameter auger for depths 7.5, 22.5, 37.5, 42.5, 67.5, and 82.5 cm around the access tube were taken. The measured gravimetric moisture contents were multiplied by apparent specific gravity to obtain the volumetric moisture content which were plotted versus the count ratio readings for each depth(Van Bavel, et al., 1961). Soil samples and neutron probe reading were collected during the whole growing season (one year) in order to cover the whole wetting and drying cycles of the soil.

3-7 Climatic data.

Rainfall (mm), minimum humidity (%), maximum humidity (%), minimum temperature (°C), maximum temperature (°C),and solar radiation (cal cm^{-2} day^{-1}) were collected from the weather station at the University of Jordan Experimental Station. The mean minimum and the mean maximum temperature for the warmest month (August) in nearby Deir-Alla station are 23.17 °C and 39.47 °C, respectively.

3-8 Actual consumptive use measurements.

The neutron probe (Campbell Pacific Nuclear, model 503) was used to measure the moisture content in the soil at 7.5, 22.5, 37.5, 52.5, 67.5, and 82.5 cm to represent the whole 90 cm soil layer. Actual evapotranspiration for mature banana (ETa) were measured using the depletion method . The values obtained by this method were the average of the three measurements of the three access tubes. Soil water measurements were taken directly before and after 48 hours of each irrigation at the six depths. Evapotranspiration rate was calculated according to the method developed by Calude (1959), and FAO (1977) using the following formula :

$$ET = [\sum_{i=1}^{n} (Pv1_i - Pv2_i)\ s_i]/\Delta t$$

where,

ET = evapotranspiration (mm . day^{-1}),

n = number of soil layers sampled in the effective root zone,

$Pv1_i$ and $Pv2_i$ = volumetric moisture content at the first and second measurements of irrigation in the i-th layer, respectively,

s_i = the thickness of i-th layer (mm),

Δt = the time interval between irrigation (days).

Evapotranspiration during the 48 hours after irrigation was considered as potential evapotranspiration and was measured using class-A pan evaporation multiplied by the appropriate pan coefficient (Kp).

3-9 Potential evapotranspiration measurements.

3-9-1. Lysimeter method.

A drainage type lysimeter (2.0m x 2.0m x 2.0m) was used to determine the potential evapotranspiration with grass as a reference crop. Grass was planted in the lysimeter with its buffer zone (4000 M^2). The consumptive use was calculated according to the following water balance equation :

$$ET = I + R - D \pm \Delta SM$$

where,

ET = the evapotranspiration (mm),

I = amount of irrigation water (mm),

R = rainfall (mm).

D = drainage water (mm), and

ΔSM = change in soil water content (mm).

3-9-2. Class A-pan Evaporation Method.

The ETP using class-A pan evaporation was estimated using the following relationship:-

$$ETP = Kp \times Ep$$

where,

ETP = potential evapotranspiration (mm),

Ep = class-A pan evaporation (mm), and

Kp = pan coefficient.

Weekly pan evaporation using screen covered class-A evaporation pan was measured from nearby pan.

3-9-3. Jensen - Haise.

Jensen and Haise (1963) and Hansen et al., (1977) estimated ETP using the following equation :

$$ETP = Ct\ (Ta - Tx)\ Rs \times 10/\lambda$$

where;

ETP = potential evapotranspiration in mm/day,

Ct = empirical coefficient,

Ta = temperature in °C,

Tx = the intercept of temperature axis,

Rs = incident solar radiation in langleys/day,

λ = 595 - 0.51 T,

The values of Ct and Tx are constants in a given area and were determined using the following equation :

$$Ct = 1/(c1 + c2\ CH)$$

where;

$$CH = 50\ mb/(e2 - e1),$$

$$c1 = .38 - (2\ ^{\circ}C \times El\ (m)/305)$$

$c2 = 7.6\ ^{o}C$,

e2,e1 are saturation vapor pressure (e_s) of water at mean maximum and mean minimum temperature respectively for the warmest month of the year in a given area.

$e_s = 1.3329 \ \exp.[21.07 - 5336.0 / (T + 273.1)]$

T = mean temperature in °C.

$Tx = -2.5 - 0.14(e2 - e1) - EL / 550$

EL = elevation in m .

3-9-4. Modified Blaney and Criddle formula and f factor

Blaney and Morin (1942) first developed an empirical equation relating evapotranspiration to mean air temperature, average relative humidity, and mean percentage of day time hours. This equation was later modified by Blaney and Criddle (1962) and Blaney et. al (1952). The equation in metric units is as follow :

$$ETPBC = K\ p\ (45.7\ t + 813)/100$$

where;

ETPBC = consumptive use of crop in mm/month,

K = empirical coefficient,

t = mean monthly temperature (°C),

p = percentage of daylight hours of the year occurring during a particular month.

The Soil Conservation Service (1967) modified the empirical coefficient (K) as :

$$K = Kt \times Kc$$

where;

Kc = monthly growth stage coefficient,

Kt = climatic coefficient calculated as follow :

$$Kt = 0.03114\ t + 0.24\ .$$

Blaney and Criddle f factor (ETPf) was determined using the following equation :

$$ETPf = Kt\ .\ p(45.7\ t + 813)/100$$

t = mean monthly temperature (^{o}C)

3-9-5. FAO Blaney-Criddle formula.

The general form of FAO Blaney-Criddle formula is

$$E_{to} = \{\ a + b\ [P(0.46T + 8.13)]\}\ [1 + 0.1(Elev/1000)]$$

where;

E_{to} = estimated evapotranspiration from a grass reference crop in millimeters per day for the period considered,

P = mean daily percentage of total daytime hours for a given time period and latitude.

a & b= correction factors where,

a = 0.0043(RHmin) - Nratio - 1.41

b = 0.81917 - 0.0040922 (RHmin) + 1.0705 (Nratio) + 0.065649 (Uday) - 0.0059684 (RHmin) (Nratio) - 0.005967 (RHmin) (Uday).

RHmin = mean daily minimum relative humidity in percent,

Nratio = mean ratio of actual to possible sunshine hours,

Uday = mean daytime wind speed in meters per second at 2 m height,

In areas where only 24-hr measurements of wind are available, day-time wind speed can be estimated as

$$Uday = U24\ (Uratio)/43.2(1 + Uratio)$$

where U24 is the 24 hr wind speed in Km/day and Uratio is the ratio of day-time to night-time wind speeds.

The N ratio can be estimated as :

$$Nratio = 2.0(R_s/R_a) - 0.5$$

R_s = measured or estimated global solar radiation in millimeters per day water equivalent,

R_a = extraterrestrial short wave solar radiation in millimeters per day water equivalent.

Elev = is the site elevation in meters above mean sea level.

Doorenbos and Pruitt (1977) suggested using a value of 2.0 for Uratio where determinations of the day/night wind ratio are unavailable.

3-9-6. Hargreaves method.

Hargreaves in 1977 developed an equation for estimating ETP as follows :

$$Et_g = 0.135\ (T + 17.78)\ Rs/\lambda$$

where;

Et_g = reference crop consumptive use, well watered grass in mm/day,

T = average daily temperature (°C),

Rs = incident solar radiation (langleys/day),

λ = latent heat of water (cal/g) = 595 - 0.51 T.

3-9-7. Hargreaves - Samani method.

Hargreaves and Samani (1982) modified Hargreaves method using the following equation:

$$ETP = 0.0075 \times T°F \times KT \times RA \times TD^{\frac{1}{2}}$$

where,

ETP = potential evapotranspiration (mm/day)

T°F = mean temperature for the period in degrees Fahrenheit (32 + 1.8 x T°C).

KT = a coefficient of temperature difference or range between mean maximum and mean minimum temperature

$= (0.035 \times (100 - RH)^{1/3}$.

RH = mean monthly relative humidity in percent .

RA = extraterrestrial radiation in mm/day.

TD = mean maximum minus mean minimum temperature.

3-10 Crop coefficient .

Crop coefficients were determined using the following equation :

$$Kc = ETa/ETP$$

where,

ETa = actual evapotranspiration (mm),

ETP = potential evapotranspiration for grass using lysimeter or estimated using class A-pan, modified Blaney-Criddle formula, Blaney-Criddle f, FAO-Blaney - Criddle, Jensen - Haise, Hargreaves-Samani, Jensen-Haise, and Hargreaves methods.

4.0 RESULTS AND DISCUSSION

4-1. Soil properties .

Selected soil physical and chemical properties are presented in Table 1. Soil texture is sandy clay loam.

4-2. Calibration curves.

Linear regression equations and correlation coefficient (R^2) for the neutron probe calibration curves for 0-15, 15-30 , 30-45 cm depths, and for 45-60, 60-75, and 75-90 cm depths are shown in figure 2a and 2b, respectively.

4-3.Soil characteristic curves .

Soil water characteristic curves for 0-15, 15-30, and 30-45 cm depths, and for 45-60, 60-75, and 75-90 cm depths are shown in Figure 3 and 4, respectively.

4-4. Climatic Data .

Rainfall (Rn, mm), minimum temperature (Tmin,°C), maximum temperature (Tmax,°C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), wind velocity (U, Km/day), and incident solar radiation (Rs, cal./cm.day) were taken from the meteorological station of the University Experiment Station are presented in appendix I Table 1.

4-5. Yield and plant parameters.

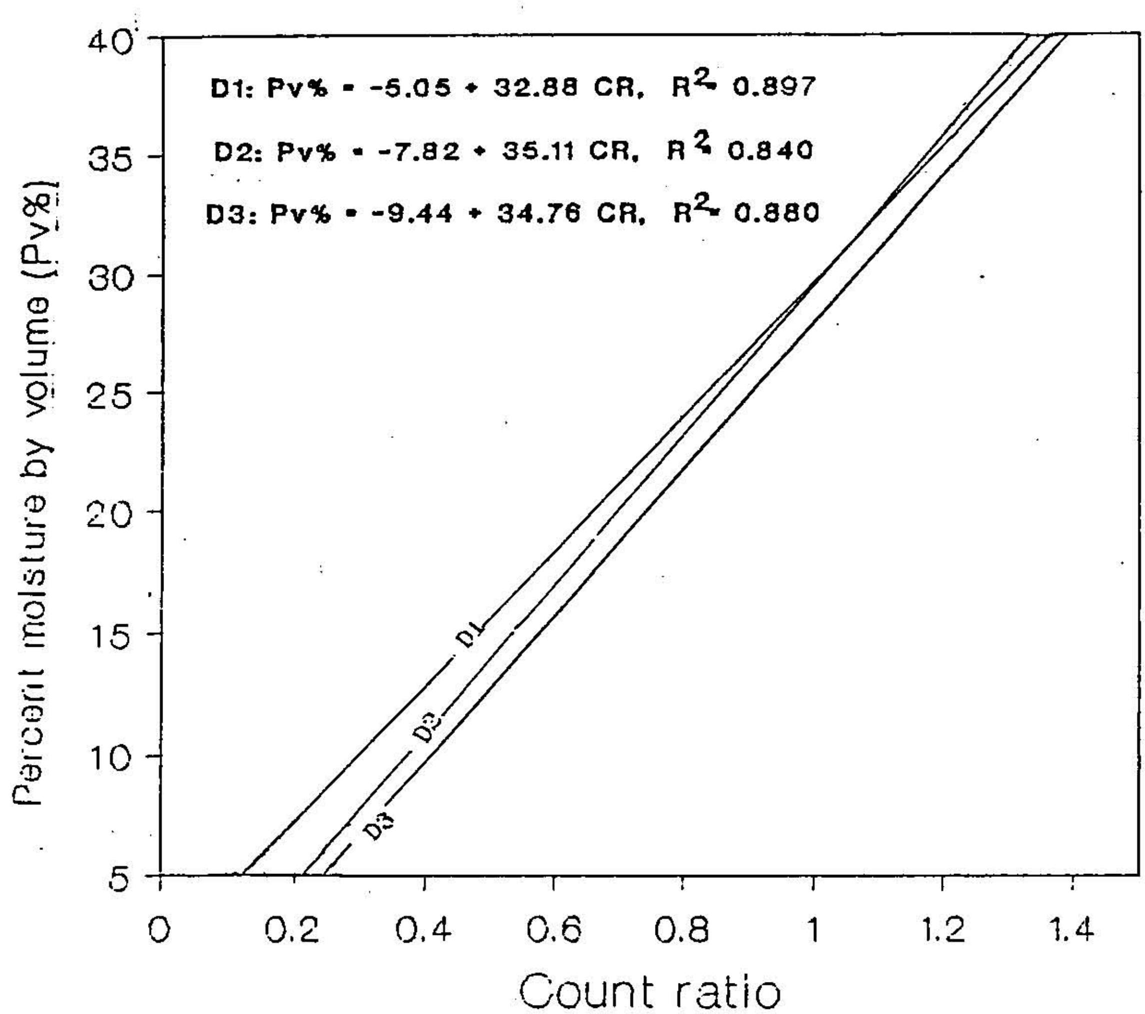


Figure (2a) Neutron probe calibration curves for 0-15 (D1), 15-30 (D2) and 30- 45 cm (D3) soil depths for the experimental site at the University of Jordan Experimental Station.

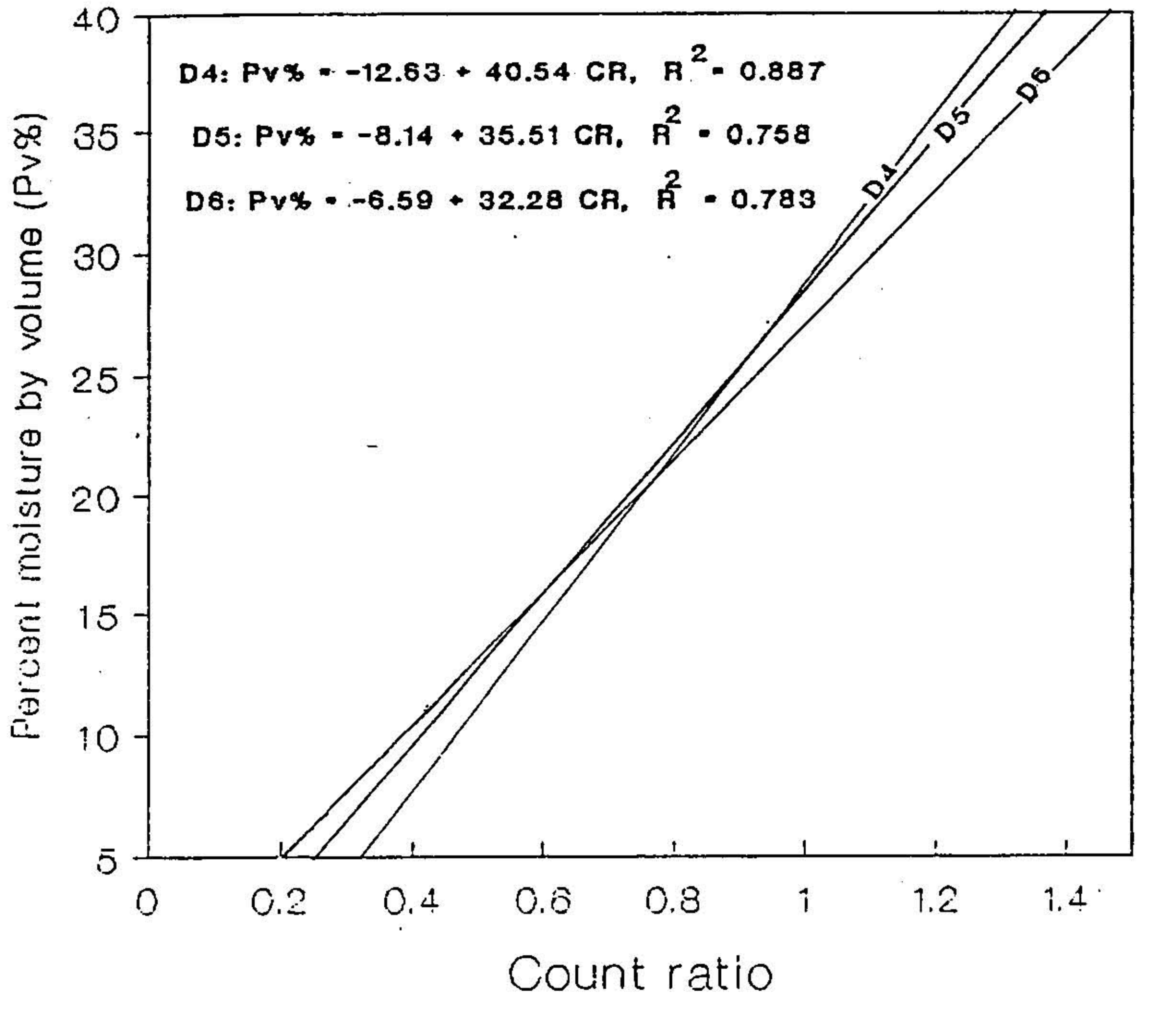
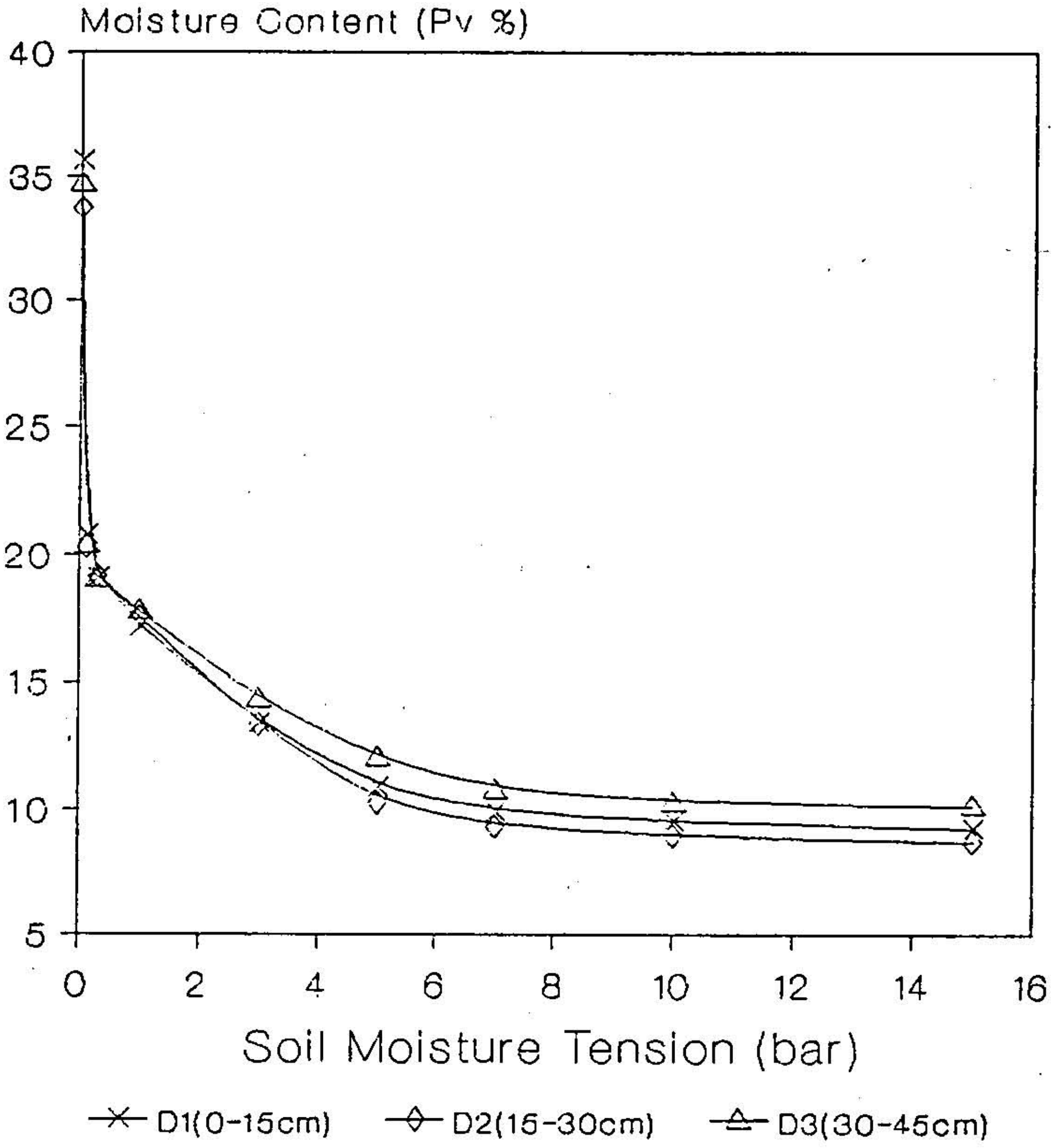


Figure (2b) Neutron probe calibration curves for 45-60 (D4), 60-75 (D5), and 75-90 cm (D6) soil depths for the experimental site at the University of Jordan Experimantal Station.



Figure(3) Soil-water characteristic curves for 0-15 (D1), 15-30 (D2) and 30- 45 cm (D3) soil depths for the experimental site at the University of Jordan Experimental Station.

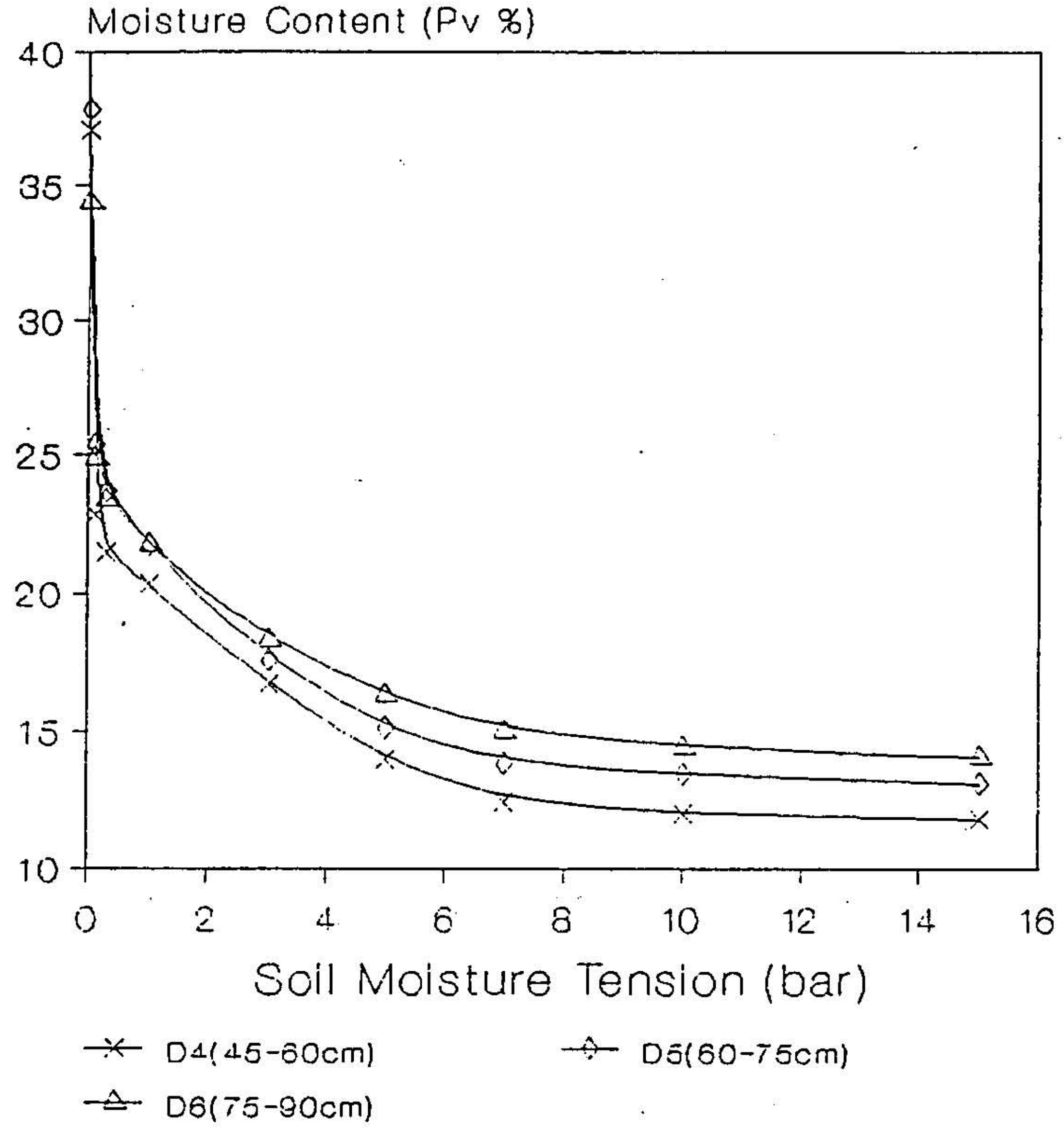


Figure (4) Soil-water characteristic curves for 45-60 (D4), 60-75 (D5) and 75-90cm (D6) soil depths for the experimental site at the University of Jordan Experimental Station.

Table 2. Total water applied, actual evapotranspiration (ETa) irrigation efficiency (IE), average banana yield, plant growth parameters water use efficiency (WUE) under the three irrigation treatments.

Treatments	T1 50%	T2 100%	T3 150%	F - test
Water applied (mm/year)	1064.18a	1739.05b	2413.93c	*
ETa (mm/year)	941.06a	1152.50b	1310.89c	*
IE (%)	88.40a	66.30b	54.30c	*
Bunch weight (kg)	3.12a	9.97b	11.14b	*
Hands per bunch	6.33a	8.67ab	9.75b	*
Fingers per bunch	75.27a	133.18b	136.17b	*
Pseudostem height(cm)	216.75a	251.32b	263.08b	*
Pseudostem girth(cm)	48.70a	57.28b	58.92b	*
Yield (ton/ha)	3.47a	33.11b	37.12b	*
W.U.E (kg/m^3)	0.36a	2.87b	2.82b	*

* : significant difference at 0.05 level, according DMRT, along each row, values followed by the same latter are not significantly difference at 5% level, according DMRT.

4-5-2 Banana Yield .

Banana yields as affected by irrigation treatments were 3.47, 33.11, and 37.12 ton/ha for T1, T2, and T3,respectively. Results indicated that banana yield had increased with the increase in amounts of water added. Similar results were reported by Krishnan and Shanmugavelu (1980), Trochoulias (1973), and Martinez (1986). Yield of T2 and T3 were significantly higher than T1. The percent increase in yield of T2 and T3 compared to T1 were 856.9, and 964.13 %, respectively. No significant differences between yield of T2 and T3 were found. This indicated that although relatively high amount of water was added to T1 (1064mm), the yield was very low (3.47 ton/ha). Increasing the water to 1739 mm (T2) had increased the yield greatly (33 ton/ha); Any further increase in amount of water had no significant affect on yield.

4-5-3 Pseudostem height

Effect of irrigation treatments on Pseudostem height was similar to the effects of irrigation treatments on bunch weight and banana yield. Pseudostem height were 216.75cm, 251.32cm, and 263.08 cm for T1, T2, and T3, respectively. These findings are similar to results reported by Krishnan and Shanmugavelu (1980), and Trochoulias (1973). Pseudostem height of T2 and T3 were significantly higher than T1. The percent increase in the sucker height of T2 and T3 compared to T1 were 15.95%, and 21.37 %. No significant differences applied in this treatment was not sufficient for leaching the soil root zone, therefore the plant growth parameters were adversely affected. Reducing the IE to 66% (T2) cased increased the yield by 89.52%, but reducing IE to 54% gave no significant effect on yield.

4-5-6. Water use efficiency (WUE).

Water use efficiency is the yield of marketable crop production per unite of water used in evapotranspiration. WUE were 0.36, 2.87, and 2.82 Kg/m^3 for T1, T2, and T3, respectively (Table 2). This indicated that the WUE responded to the amounts of water applied. Which is in agreement with the findings of Lahav and Kalmar (1988) in the Jordan Valley. Doorenbos and Kassom (1979) reported that economic WUE values for bananas ranged from 2.5 to 4 Kg/m^3. While Hegde and Srinivas (1988) found the WUE values ranged from 2.8 to 3.7 Kg/m^3 for different irrigation treatments in India. The WUE of T2 and T3 were significantly higher than T1. The percent increase in WUE of T2 and T3 compared to T1 were 697.2%, and 683.3%, respectively. No significant differences between the WUE of T2 and T3 at 5% level were found.

4-5-6. Actual Evapotranspiration of mature bananas by depletion method (ETa).

Actual annual evapotranspiration (ETa) values of banana plant determined by the depletion method were 941 mm, 1152 mm, and 1310 mm for T1, T2, and T3, respectively (Table 2). Total ETa increased with the increase of applied water. An

Table 3. Average daily evapotranspiration (mm/day) measured by depletion method for mature banana plant under the three irrigation treatments during 1991.

Period	Days	T1	T2	T3
1-10 Jan.	10	2.75	2.62	2.89
11-20 Jan.	10	2.24	2.06	2.34
21-31 Jan.	11	1.43	1.92	1.86
1-10 Feb.	10	2.86	2.61	2.74
11-20 Feb.	10	2.21	1.91	2.14
21-28 Feb.	8	1.94	2.32	2.35
1-10 Mar.	10	1.88	1.91	2.11
11-20 Mar.	10	1.97	2.14	1.98
21-31 Mar.	11	2.10	2.40	2.52
1-10 Apr.	10	2.64	3.02	4.10
11-20 Apr.	10	2.45	2.93	3.44
21-30 Apr.	10	2.85	3.64	4.07
1-10 May	10	3.74	4.28	4.30
11-20 May	10	2.70	3.84	3.70
21-31 May	11	3.60	3.94	4.14
1-10 June	10	4.04	4.44	4.95
11-20 June	10	3.19	4.51	5.47
21-30 June	10	3.69	5.16	6.88
1-10 July	10	3.71	4.92	5.44
11-20 July	10	4.22	4.95	4.85
21-31 July	11	2.90	4.60	4.59
1-10 Aug.	10	3.34	4.64	4.70
11-20 Aug.	10	2.37	4.30	4.74
21-31 Aug.	11	2.64	3.74	5.59
1-10 Sep.	10	3.52	4.28	5.70
11-20 Sep.	10	3.38	4.22	4.87
21-30 Sep.	10	3.18	4.41	4.74
1-10 Oct.	10	2.91	3.80	5.90
11-20 Oct.	10	2.00	3.25	3.24
21-31 Oct.	10	1.75	2.35	3.03
1-10 Nov.	10	2.60	2.95	3.54
11-20 Nov.	10	1.43	1.38	1.73
21-30 Nov.	10	1.80	1.32	1.86
1-10 Dec.	10	0.94	0.93	1.34
11-20 Dec.	10	0.94	1.12	1.75
21-31 Dec.	11	0.98	1.03	1.32
Total (mm)		(941.06)	(1152.50)	(1310.89)

T1 = 50% of class A pan evaporation.

T2 = 100% of class A pan evaporation.

T3 = 150% of class A pan evaporation.

Table 4. Average daily evapotranspiration (mm/day) for mature banana on monthly basis under the three irrigation treatments.

Period	Days	Irrigation treatments		
1991		T1	T2	T3
Jan.	31	2.12	2.19	2.35
Feb.	28	2.36	2.28	2.41
Mar.	31	2.00	2.12	2.21
Apr.	30	2.68	3.20	3.87
May	31	3.35	4.02	4.04
June	30	3.64	4.70	5.77
July	31	3.59	4.82	4.95
Aug.	31	2.78	4.21	5.02
Sep.	30	3.36	4.30	5.10
Oct.	31	2.20	3.11	4.02
Nov.	30	1.94	1.88	2.38
Dec.	31	0.95	1.03	1.46
Total(mm)		(941.06)	(1152.50)	(1310.89)

T1 = 50% of class A pan evaporation.
T2 = 100% of class A pan evaporation.
T3 = 150% of class A pan evaporation.

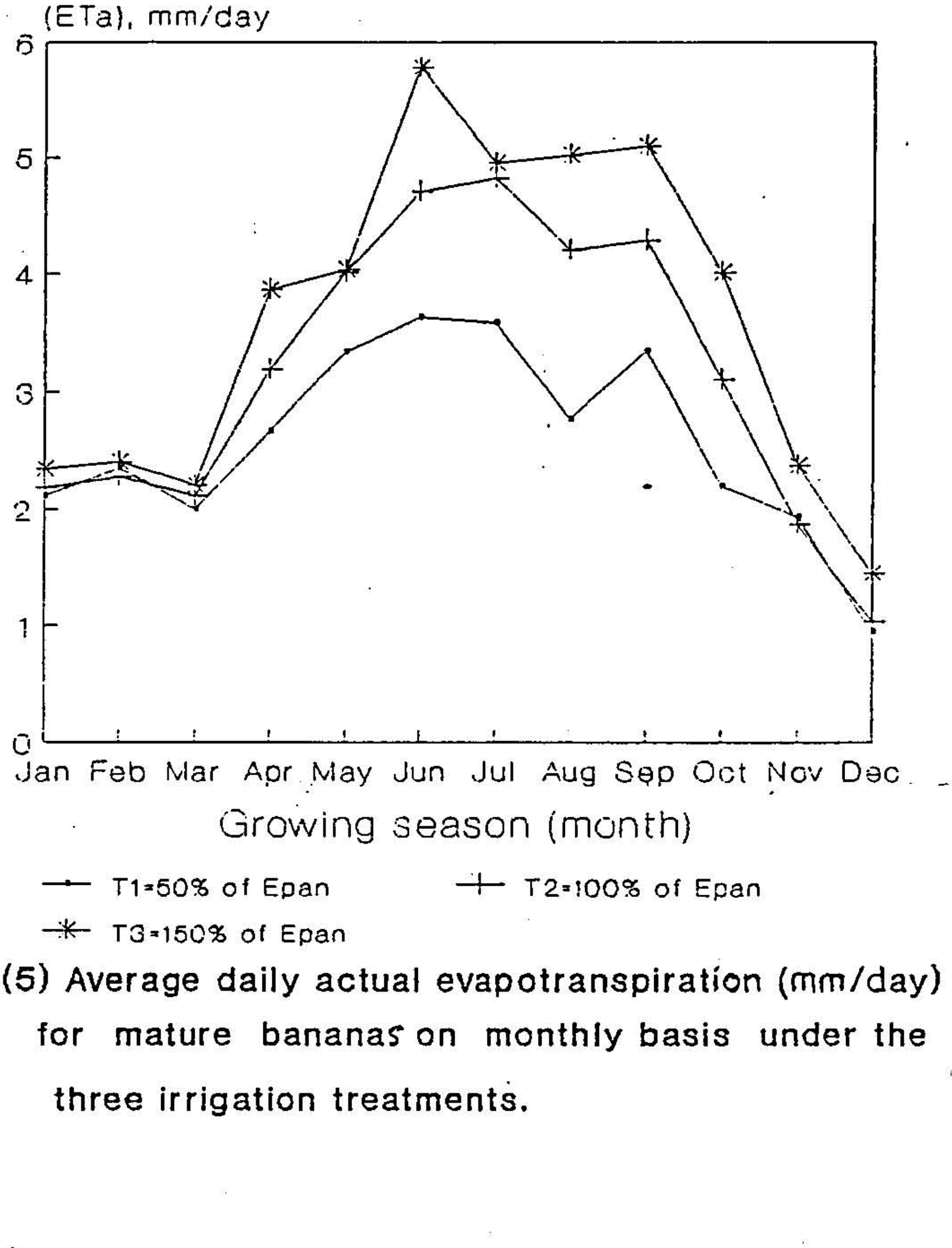


Figure (5) Average daily actual evapotranspiration (mm/day) for mature bananas on monthly basis under the three irrigation treatments.

treatments were low at the beginning of the year then increased until they reached maximum values during June to September followed by gradual decline until they reached minimum values during December. These fluctuations in the ET values are due to the climatic changes during the growing season.

4-6. Prediction of potential evapotranspiration (ETP) and crop coefficients (Kc).

Potential evapotranspiration (ETP) was measured directly by a drainage lysimeter (ETPlys) with grass as a reference crop and by screen class-A pan evaporation. It was also estimated by six empirical equations which used various meteorological data.

Table 5 shows the average daily ETa and corresponding Kc values of bananas for T2 and ETPlys. Average daily ET varied with time over the growing season (1991) for both mature banana and grass crop. Average daily ETa and ETPlys were measured at 10-days intervals.

Table 6 shows average daily ETPlys, ETa for T2 and the corresponding Kc values on monthly basis.

Average daily ETa for mature banana and estimated monthly potential evapotranspiration calculated using Hargreaves (ETP_H), Hargreaves and Samani (ETP_{H-S}), Jensen-Haise (ETP_{J-H}), Modified Blaney-Criddle (ETP_{B-C}), Blaney-Criddle factor (ETP_f), and FAO Blaney-Criddle (ETP_{FAO}) and their corresponding Kc values are shown in table 7 for

Table 5. Average daily actual evapotranspiration (ETa) measured by depletion method for mature banana; with 100% of Epan irrigation level, average daily potential evapotranspiration of grass measured by lysimeter (ETPlys), and crop coefficient value (Kc).

Period	Days	ETlys mm/day	ETa mm/day	Kc ETa/ETlys
1 - 10 Jan.	10	3.50	2.62	0.75
11 - 20 Jan.	10	2.40	2.06	0.86
21 - 31 Jan.	11	2.40	1.92	0.80
1 - 10 Feb.	10	2.40	2.61	1.09
11 - 20 Feb.	10	2.40	1.91	0.80
21 - 28 Feb.	8	1.30	2.32	0.78
1 - 10 Mar.	10	1.30	1.91	1.47
11 - 20 Mar.	10	2.50	2.14	0.87
21 - 31 Mar.	11	4.40	2.40	0.54
1 - 10 Apr.	10	4.40	3.02	0.69
11 - 20 Apr.	10	4.40	2.93	0.67
21 - 30 Apr.	10	4.40	3.64	0.83
1 - 10 May	10	4.20	4.28	1.02
11 - 20 May	10	3.30	3.84	1.02
21 - 31 May	11	5.00	3.94	1.16
1 - 10 June	10	5.40	4.44	0.95
11 - 20 June	10	7.10	4.51	0.55
21 - 30 June	10	7.50	5.16	0.69
1 - 10 July	10	7.20	4.92	0.68
11 - 20 July	10	4.30	4.95	1.15
21 - 31 July	11	4.00	4.60	1.15
1 - 10 Aug.	10	4.40	4.64	1.05
11 - 20 Aug.	10	5.50	4.30	0.78
21 - 31 Aug.	11	5.70	3.74	0.66
1 - 10 Sep.	10	5.70	4.28	0.75
11 - 20 Sep.	10	5.40	4.22	0.78
21 - 30 Sep.	10	4.10	4.41	1.08
1 - 10 Oct.	10	4.10	3.80	0.93
11 - 20 Oct.	10	4.10	3.25	0.79
21 - 31 Oct.	10	3.90	2.35	0.60
1 - 10 Nov.	10	3.70	2.95	0.80
11 - 20 Nov.	10	2.90	1.38	0.48
21 - 30 Nov.	10	3.40	1.32	0.39
1 - 10 Dec.	10	3.40	0.93	0.27
11 - 20 Dec.	10	3.00	1.12	0.37
21 - 31 Dec.	11	2.00	1.03	0.52
Total (mm)		(1476.21)	(1152.50)	

ETa = 100% of class A pan evaporation.

Table 6. Average daily actual evapotranspiration (ETa) for mature bananas with 100% of Epan, average daily potential evapotranspiration for grass (ETPlys) on monthly basis, and crop coefficient values during the growing season.

period 1991	Days	ETPlys mm/day	ETa mm/day	Kc ETa/ETPlys
Jan.	31	2.76	2.19	0.80
Feb.	28	2.07	2.28	1.09
Mar.	31	2.79	2.12	0.76
Apr.	30	4.40	3.20	0.73
May	31	4.19	4.02	0.96
June	30	6.67	4.70	0.70
July	31	5.13	4.82	0.94
Aug.	31	5.22	4.21	0.81
Sep.	30	5.07	4.30	0.85
Oct.	31	4.03	3.11	0.77
Nov.	30	3.33	1.88	0.56
Dec.	31	2.77	1.03	0.37
Total (mm)		(1476.21)	(1152.5)	

Table 7. Average daily (mm/day) actual evapotranspiaration (ETa) for each month by depletion method for mature banana and estimated average (mm/day) potential evapotraspiration for each month by Hargreaves, Hargreaves and Samani, Jensen-Haise, modified Blaney-Criddle, f (Blaney-Criddle), FAO Blaney-Criddle, and their corresponding crop coefficient values (Kc).

Period 1991	Days	ETa mm/day	ETPH* mm/day	Kc=ETa/ETPH	ETPH-S* mm/day	Kc=ETa/ETPH-S	ETPJ-H* mm/day	Kc=ETa/ETPJ-H	ETPB-C mm/day	Kc**	ETPf* mm/day	Kc=ETa/ETPf	ETPFAO* mm/day	Kc=ETa/ETF
Jan.	31	2.19	1.63	1.34	1.75	1.25	1.74	1.26	1.94	0.83	2.34	0.93	1.62	1.36
Feb.	28	2.28	2.31	0.99	2.38	0.96	2.52	0.91	2.58	0.92	2.80	0.81	2.31	0.99
Mar.	31	2.12	2.90	0.73	3.32	0.64	3.28	0.65	3.77	0.96	3.93	0.54	2.90	0.73
Apr.	30	3.20	4.21	0.76	5.52	0.58	4.95	0.65	5.42	0.98	5.53	0.58	4.70	0.68
May	31	4.02	5.10	0.79	6.60	0.61	6.11	0.66	7.16	1.03	6.95	0.58	5.86	0.69
June	30	4.70	5.71	0.82	7.88	0.60	6.98	0.67	8.81	1.04	8.47	0.55	6.47	0.73
July	31	4.82	6.25	0.77	6.87	0.70	7.68	0.63	9.19	1.02	9.01	0.53	7.29	0.66
Aug.	31	4.21	5.77	0.73	6.27	0.67	7.10	0.59	8.47	1.01	8.39	0.50	6.34	0.66
Sep.	30	4.30	4.72	0.91	5.44	0.79	5.77	0.75	7.20	0.98	7.35	0.59	5.49	0.78
Oct.	31	3.11	3.84	0.81	4.32	0.72	4.65	0.67	6.05	0.97	6.23	0.50	4.74	0.66
Nov.	30	1.88	2.40	0.78	2.69	0.70	2.78	0.68	3.59	0.90	3.99	0.47	2.97	0.63
Dec.	31	1.03	1.79	0.57	1.31	0.79	1.90	0.54	1.86	0.84	2.22	0.46	1.65	0.62
Total (mm)		1152.5	1420.97		1656.39		1690.82		2014.63		2049.81		1595.95	

** : Kc values are obtained from the growth stage coefficient curves given in the U.S.D.A technical release No. 21, of the soil conservation service.

* : See appendix, sample of calculations. page (100, 101, 102, 103)

the same period. Average daily ETa for mature banana and adjusted pan coefficient according to Doorenbos and Pruitt (1977), and class-A pan evaporation (Epan) and Kc values are shown in table 8 on 10-days and in table 9 on monthly basis.

The ETa, ETPlys, and Epan values were compared with ETP_{B-C} (fig. 6), ETP_{FAO} (fig. 7), ETP_{J-H} (fig. 8), ETP_{H} (fig.9) ETP_{H-S} (fig. 10) , and ETP_{f} (fig. 11). All ET values had the same characteristics with response to climatic variation through the growing season.

The Kc values variation with the growing season (1991) on monthly basis for different empirical methods are shown in figure 12 (H, FAO, lys, and pan), figure 13 (f B-C, FAO, lys, and pan), figure 14 (J-H, FAO, lys, and pan), and figure 15 (H-S, FAO, lys, and pan). It is clear that Kc values had almost the same trends.

From the above mentioned figures, Kcpan values were high during Jan., Feb., Mar., and Dec.. This is because of low Epan values during that period due to low temperature and incident solar radiation (Appendix 1 Table 1). Kc values obtained from ETa and ETP_{f} were the lowest. This is due to high ETP_{f} values. The values of $Kc_{(FAO)}$, $Kc_{(H)}$, $Kc_{(J-H)}$, and $Kc_{(H-S)}$ had the same trends.

4-7. Evaluation of Estimating Methods

4-7-1. Potential evapotranspiration of grass by lysimetric method (ETPlys).

Regression analysis were made for the six estimating

Table 8. Average daily actual evapotranspiration, (ETa) measured by depletion method for mature banana with 100% of Epan, average screen class-A pan evaporation (Ep), pan coefficient (Kp), and Epan, and the corresponding Kc values during the growin season.

Period	Kp	Ep mm/day	Epan KpxEp mm/day	ETa mm/day	Kc ETa/Epan
1-10 Jan.	0.720	1.76	1.27	2.62	2.07
11-20 Jan.	0.695	2.45	1.63	2.06	1.26
21-31 Jan.	0.764	1.04	0.79	1.92	2.67
1-10 Feb.	0.720	1.59	1.14	2.61	2.68
11-20 Feb.	0.700	2.46	1.72	1.91	1.11
21-28 Feb.	0.740	2.35	1.74	2.32	1.33
1-10 Mar.	0.710	2.80	1.98	1.91	0.96
11-20 Mar.	0.690	3.30	2.28	2.14	0.94
21-31 Mar.	0.730	4.39	3.21	2.40	0.74
1-10 Apr.	0.700	4.96	3.47	3.02	0.87
11-20 Apr.	0.660	4.79	3.16	2.93	0.93
21-30 Apr.	0.650	8.24	5.36	3.64	0.68
1-10 May	0.655	9.05	5.93	4.28	0.72
11-20 May	0.650	8.24	5.38	3.84	0.71
21-31 May	0.695	7.27	5.06	3.94	0.78
1-10 June	0.655	10.27	6.73	4.44	0.66
11-20 June	0.700	9.02	6.31	4.51	0.71
21-30 June	0.695	10.28	7.14	5.16	0.66
1-10 July	0.700	9.91	6.94	4.92	0.71
11 20 July	0.700	10.03	7.02	4.95	0.71
21-31 July	0.744	8.83	6.57	4.60	0.70
1-10 Aug.	0.695	8.00	5.70	4.64	0.81
11-20 Aug.	0.700	9.08	6.36	4.30	0.68
21-31 Aug.	0.700	8.08	5.66	3.74	0.66
1-10 Sep.	0.700	7.76	5.43	4.28	0.79
11-20 Sep.	0.700	8.12	5.69	4.22	0.78
21-30 Sep.	0.700	7.76	5.43	4.41	0.74
1-10 Oct.	0.670	7.80	5.23	3.80	0.73
11-20 Oct.	0.670	5.60	3.74	3.25	0.87
21-31 Oct.	0.673	6.24	4.20	2.35	0.56
1-10 Nov.	0.680	3.46	2.35	2.95	1.25
11-20 Nov.	0.690	3.68	2.54	1.38	0.54
21-30 Nov.	0.710	3.54	2.51	1.32	0.52
1-10 Dec.	0.740	1.30	0.95	0.93	0.98
11-20 Dec.	0.740	1.35	1.00	1.12	1.12
21-31 Dec.	0.730	1.50	1.10	1.03	0.94
Total (mm)			(1450.77)	(1152.50)	

ETa = 100 % from class-A Pan evaporation .

Table 9. Average daily screen class-A pan evaporation (Epan), ETa and Kc values on monthly basis.

period 1991	Days	Epan mm/day	ETa mm/day	Kc ETa/Epan
Jan.	31	1.22	2.19	1.80
Feb.	28	1.52	2.28	1.50
Mar.	31	2.52	2.12	0.84
Apr.	30	4.00	3.20	0.80
May	31	5.44	4.02	0.74
June	30	6.73	4.70	0.70
July	31	6.83	4.82	0.71
Aug.	31	5.90	4.21	0.71
Sep.	30	5.52	4.30	0.78
Oct.	31	4.38	3.11	0.70
Nov.	30	2.47	1.88	0.76
Dec.	31	1.03	1.03	1.00
Total(mm)		(1450.77)	(1152.50)	

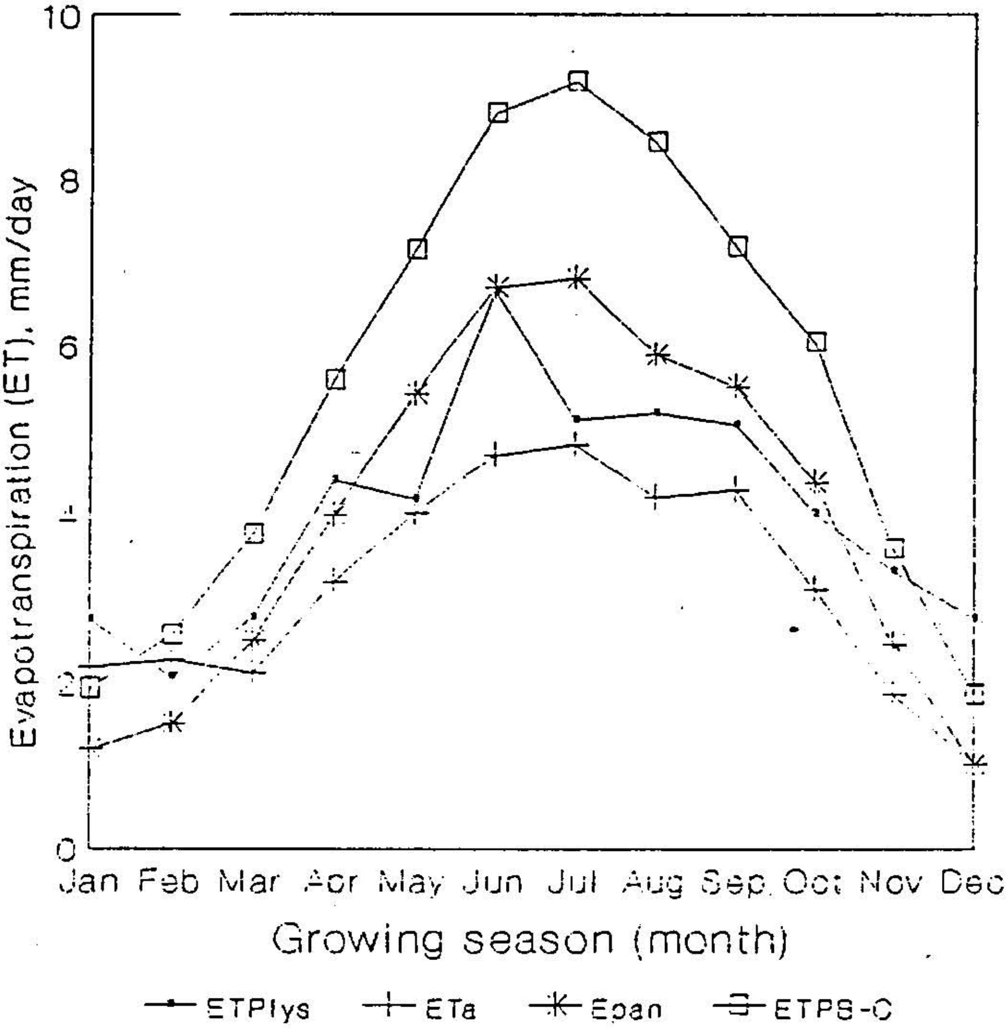
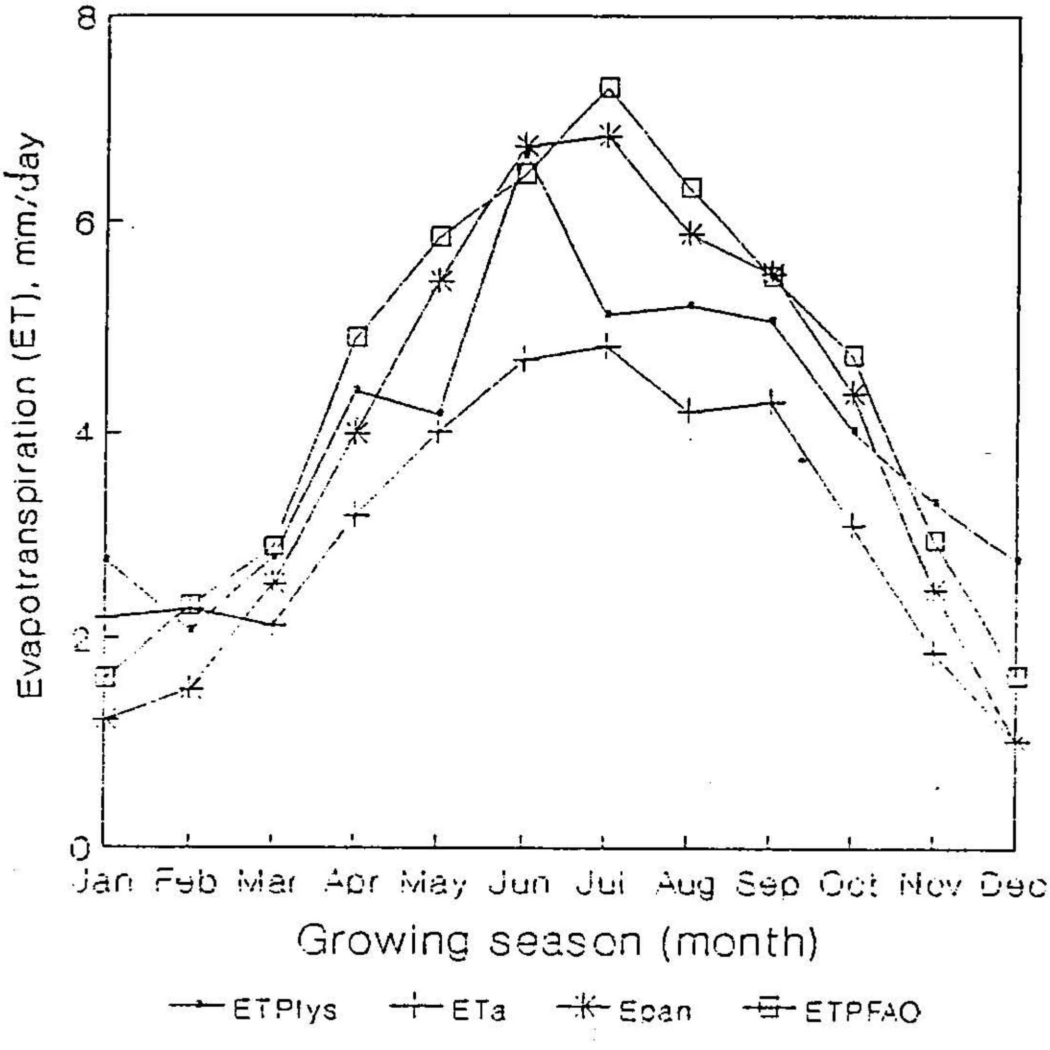
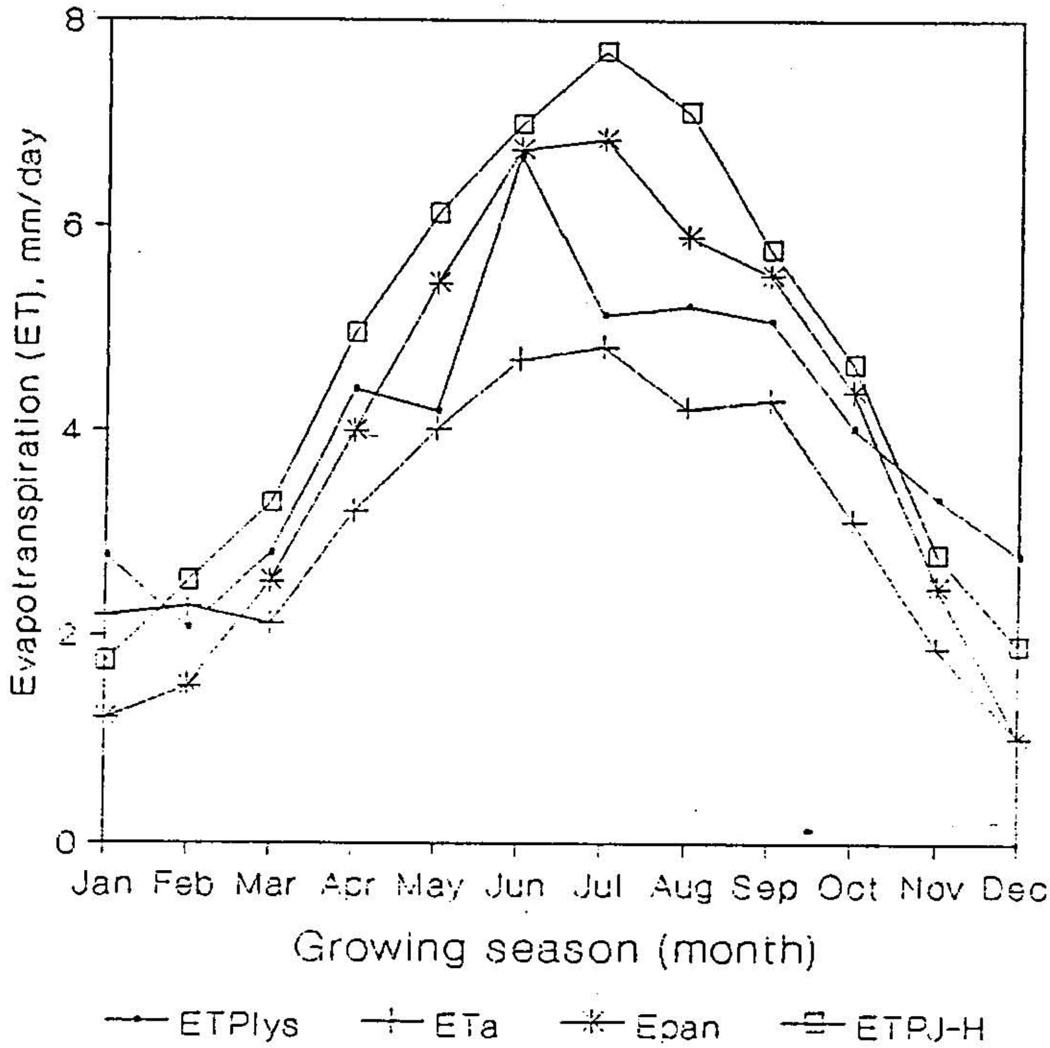


Figure (6) Mean daily ETa, ETPlys, Epan, and ETPB-C during the drowing season.



Figure(7) Mean daily ETa, ETPlys, Epan, and ETPFAO during the growing season.



Figure(8) Mean daily ETa, ETPlys, Epan, and ETPJ-H during the growing season.

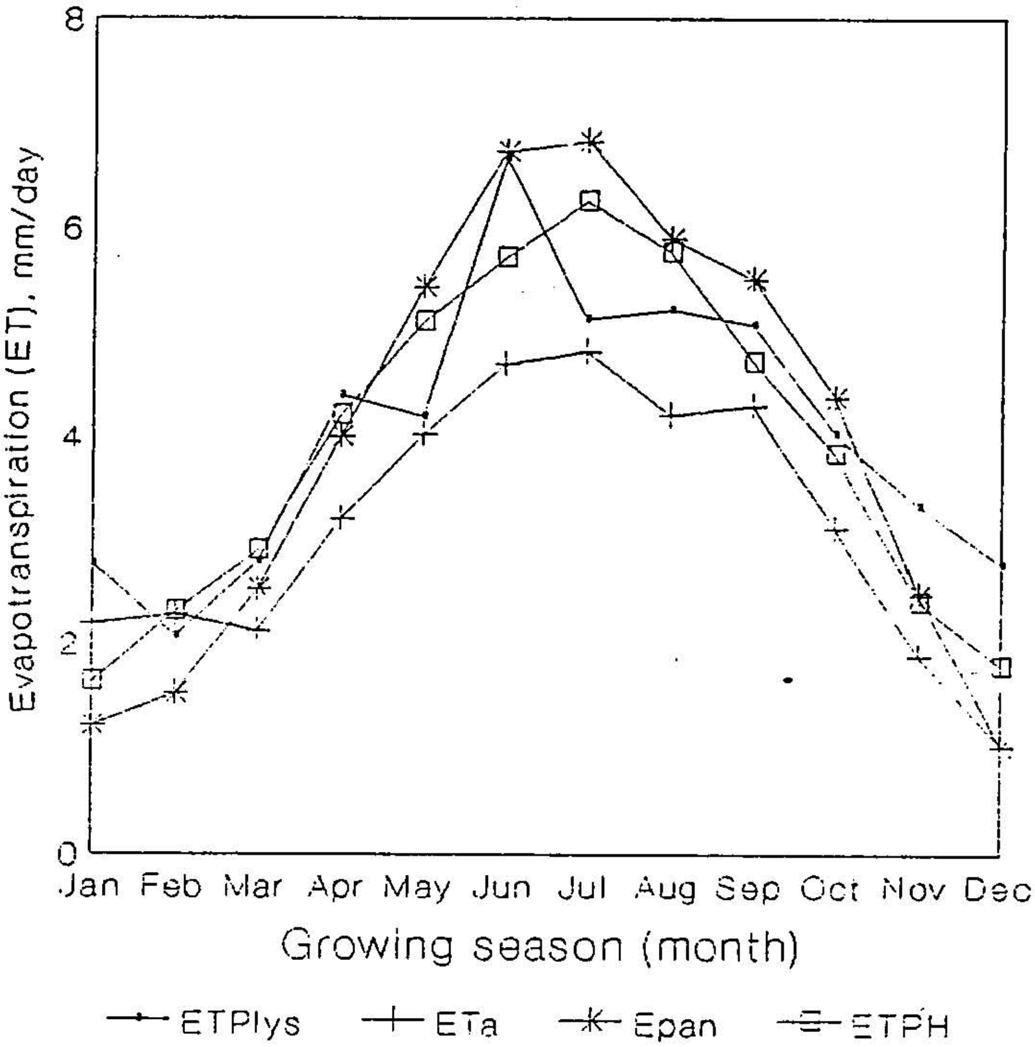


Figure (9) Mean daily ETa, ETPlys, Epan, and ETPH during the growing season.

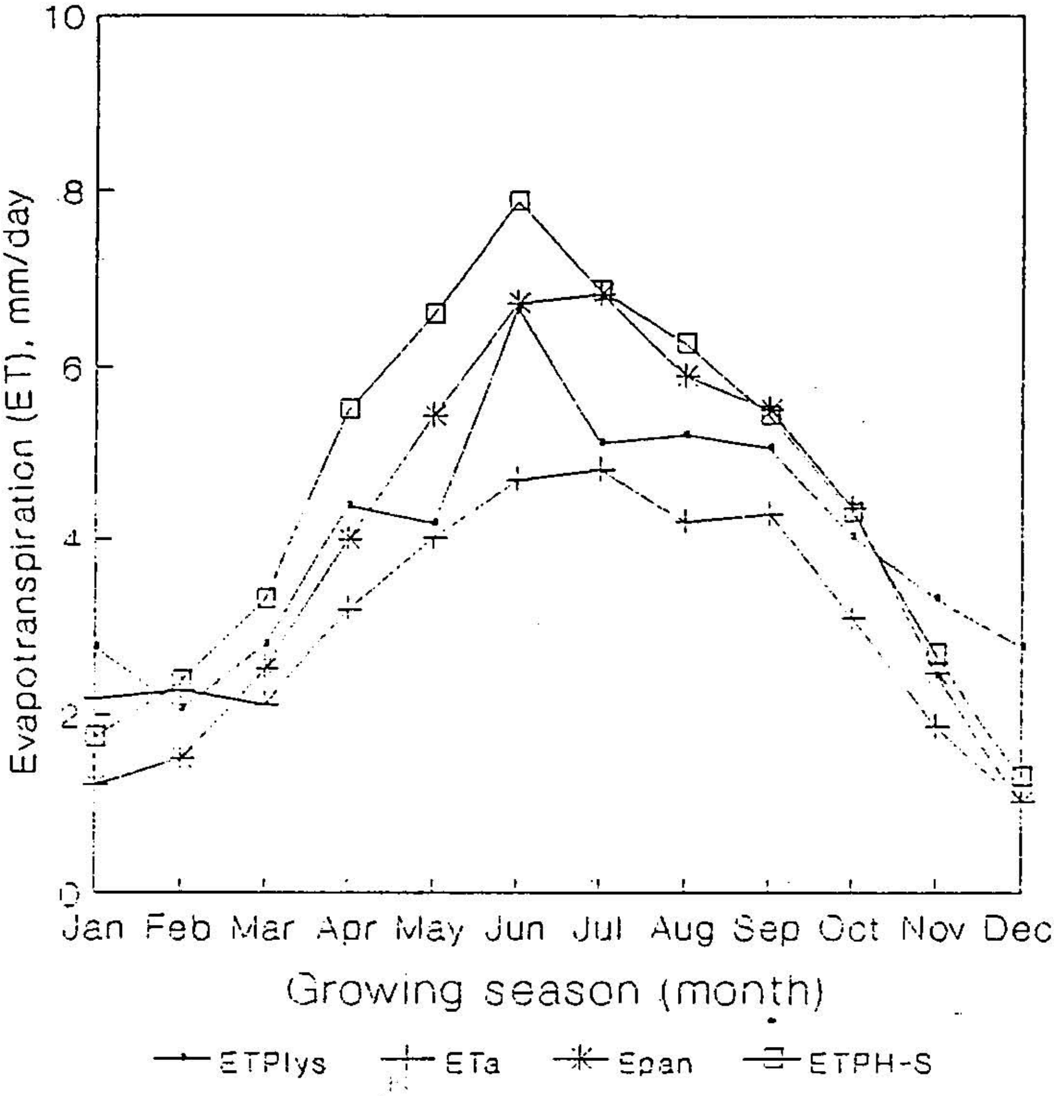


Figure (10) Mean daily ETa, ETPlys, Epan, and ETPH-S during the growing season.

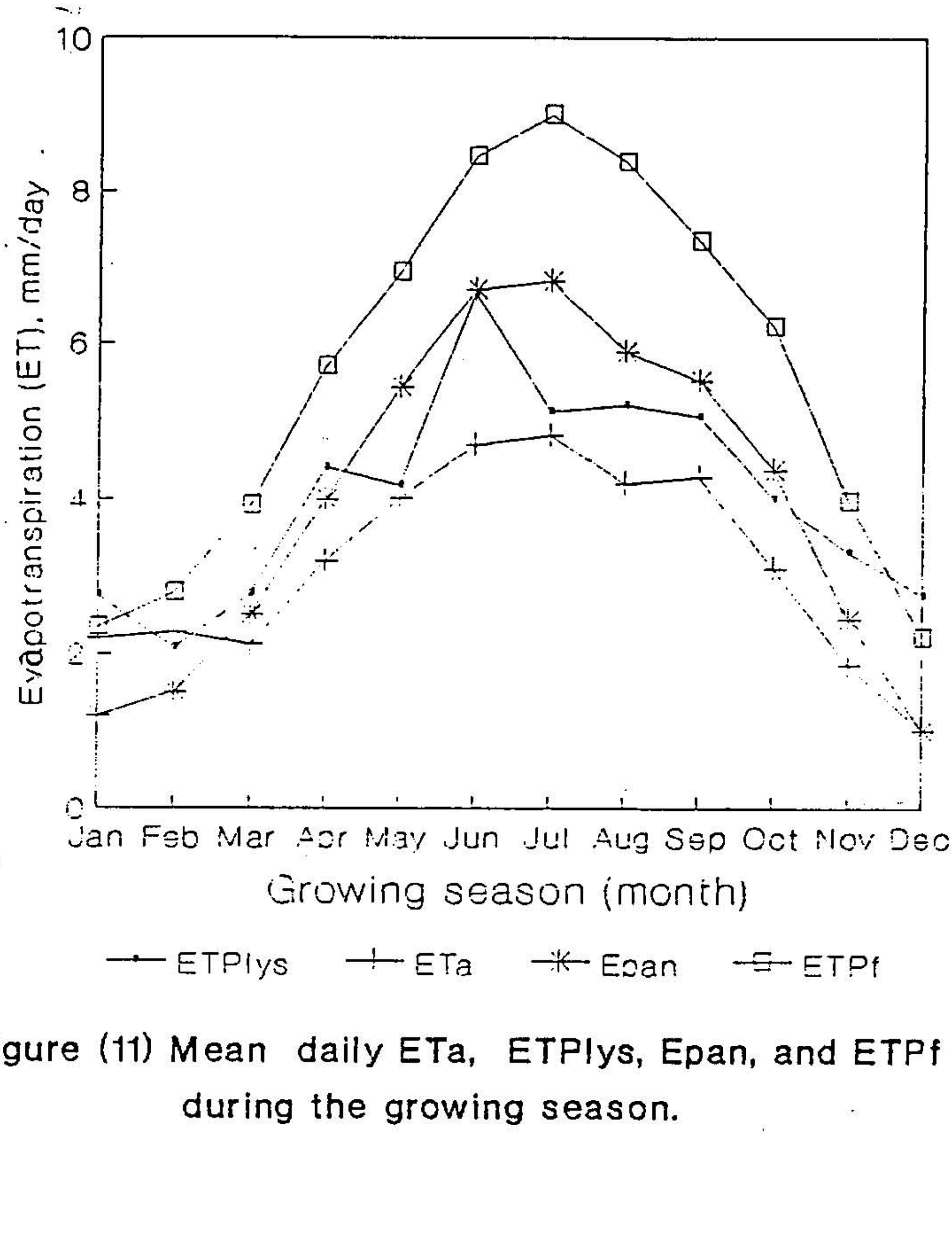


Figure (11) Mean daily ETa, ETPlys, Epan, and ETPf during the growing season.

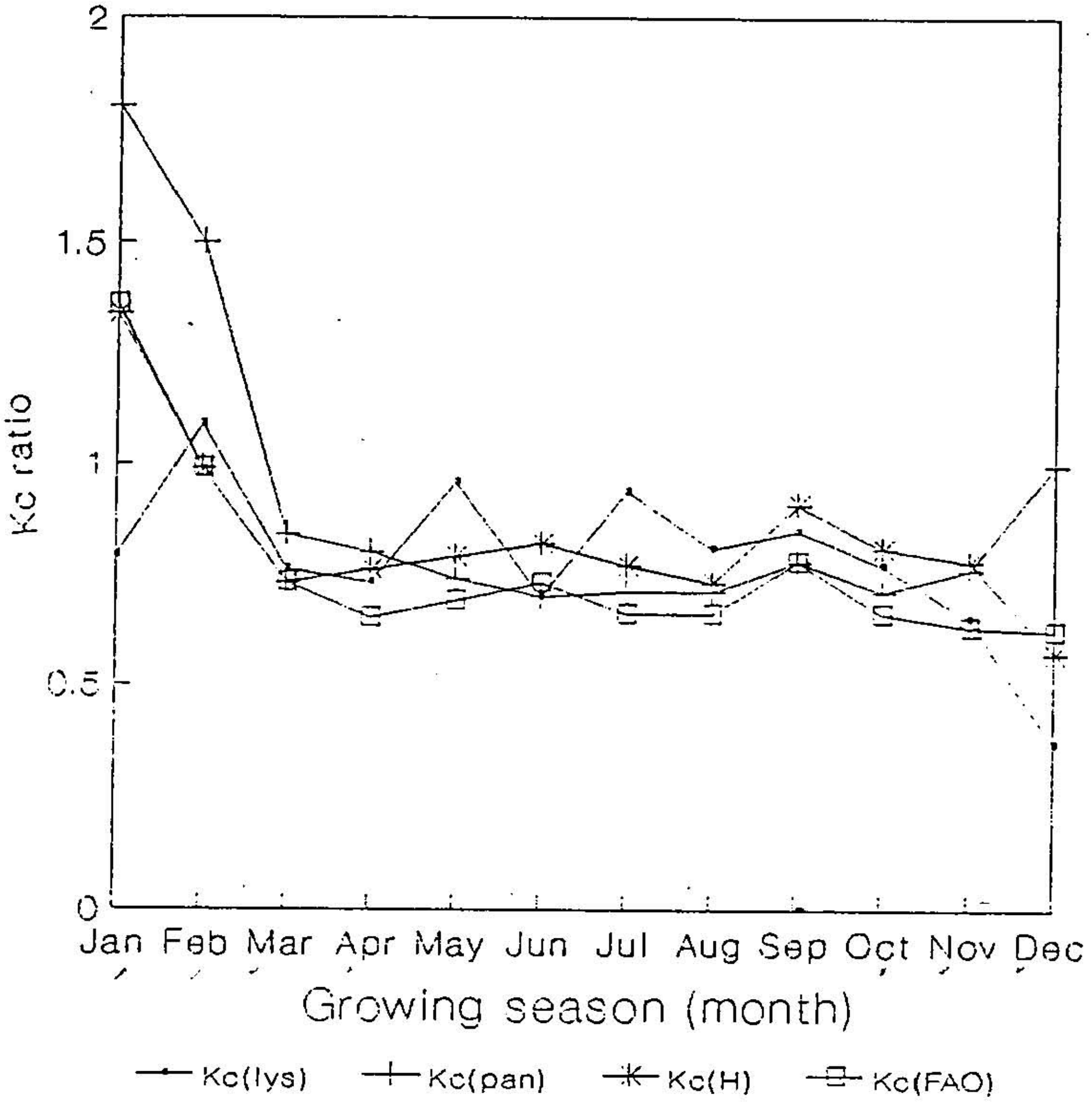


Figure (12) Crop coefficient values variation with the growing season on monthly basis interval for banana for Kc(H), Kc(FAO), Kc(lys), and Kc(pan).

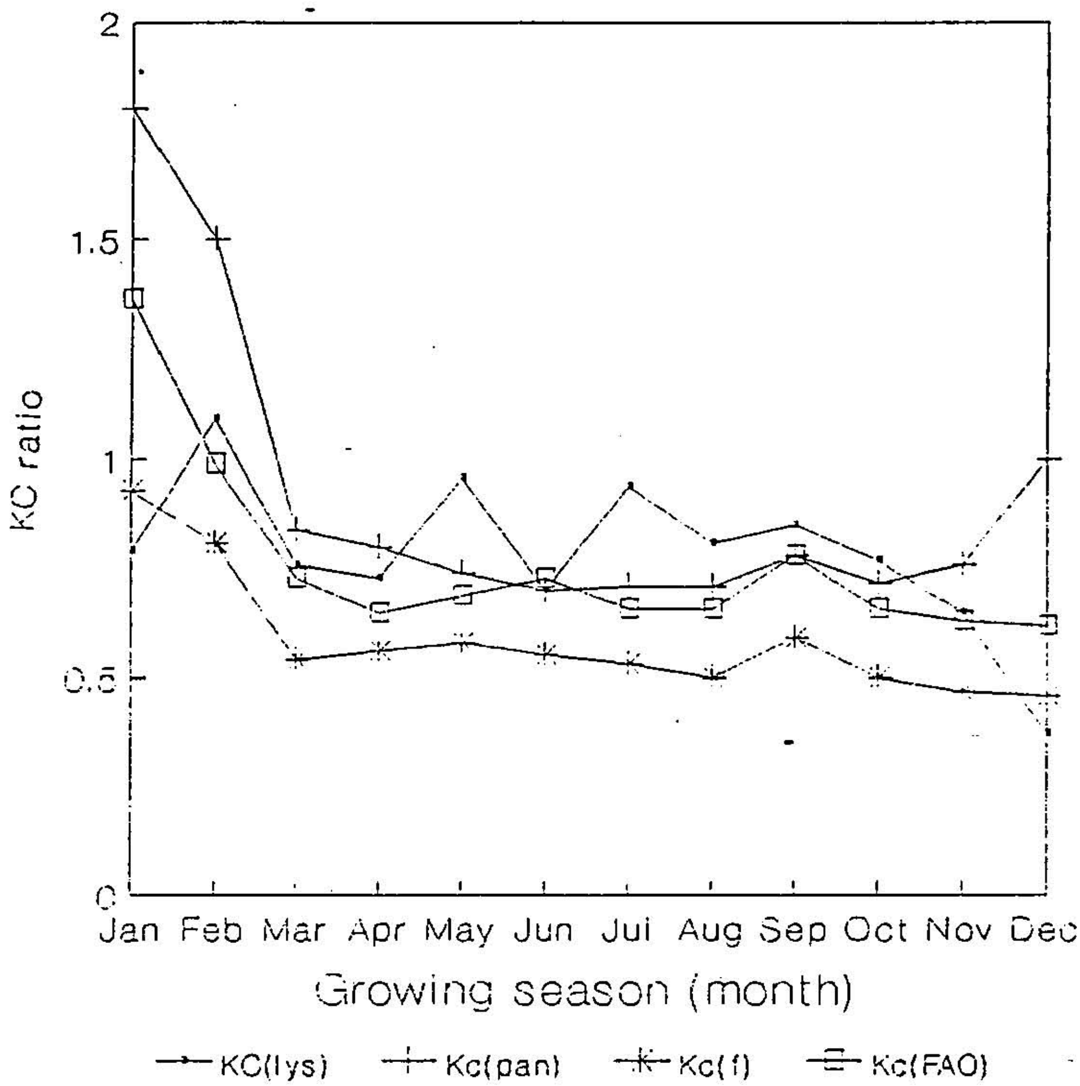


Figure (13) Crop coefficient values variation with the growing season on monthly basis interval for banana for Kc(f), Kc(FAO), Kc(lys), and Kc(pan).

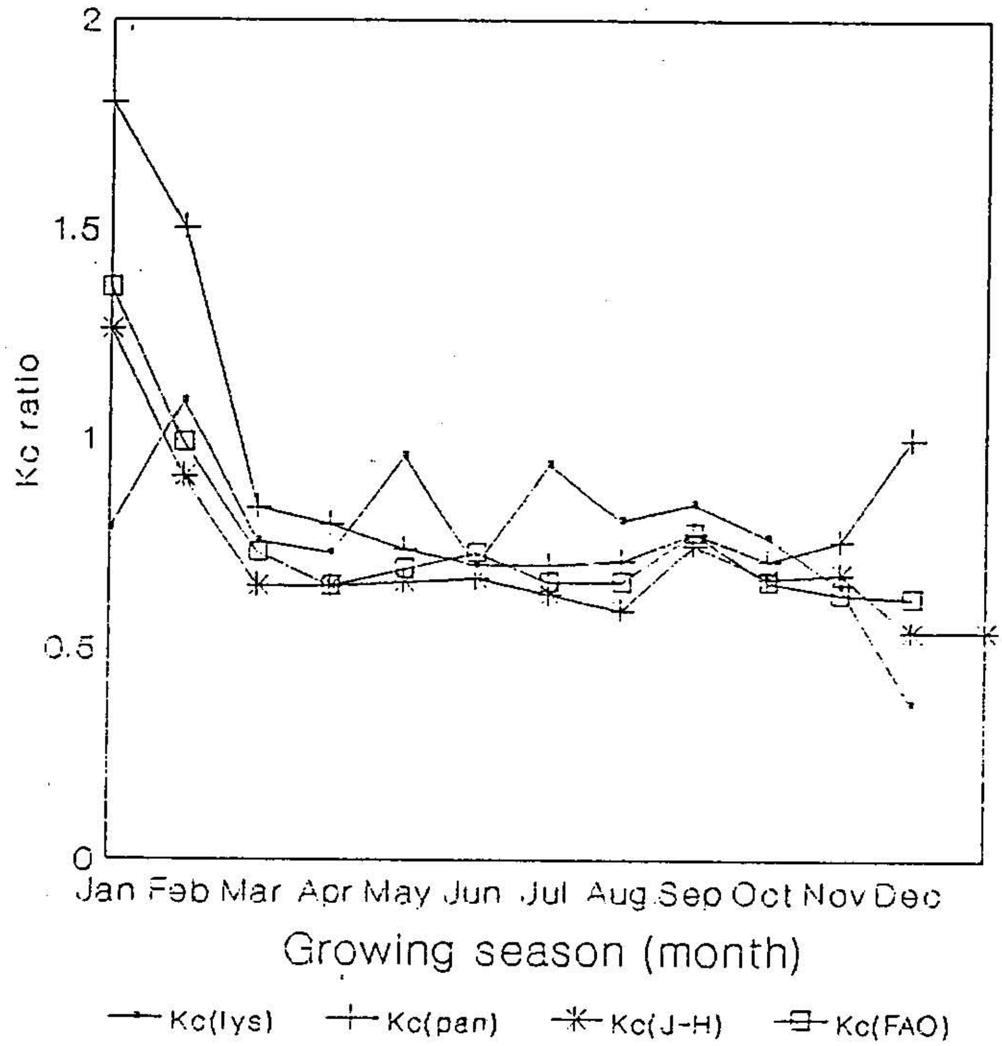


Figure (14) Crop coefficient values variation with the growing season on monthly basis interval for banana for Kc(J-H), Kc(FAO), Kc(lys), and Kc(pan).

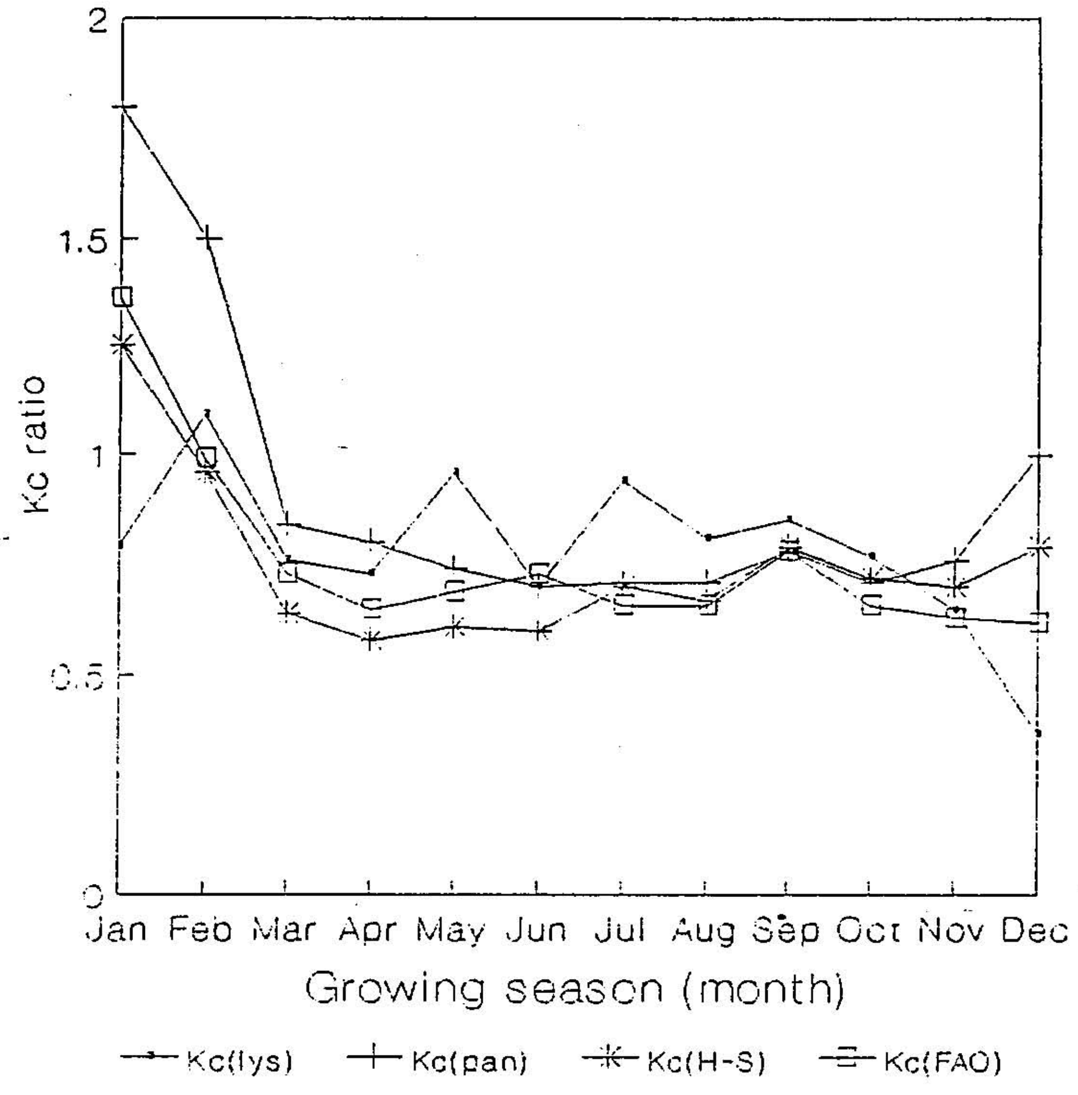


Figure (15) Crop coefficient values variation with the growing season on monthly basis interval for banana for Kc(H-S), Kc(FAO), Kc(lys), and Kc(pan).

methods compared with measured ETPlys. The measurements were the mean daily ETPlys on monthly basis. The regression coefficients for these methods are shown in table 10. The coefficients of determination (R^2) were 0.840, 0.839, 0.831, 0.803, 0.798, and 0.793 for $ETP_{(B-C)}$, $ETP_{(f)}$, $ETP_{(H-S)}$, $ETP_{(J-H)}$, $ETP_{(FAO)}$, and $ETP_{(H)}$, respectively. The results show that $ETP_{(B-C)}$, $ETP_{(f)}$, and $ETP_{(H-S)}$ have similar and higher (R^2) values, because they used similar climatic factors.

4-7-2. Actual evapotranspiration of mature banana (ETa).

Regression analysis were made for the six estimating methods compared with measured (ETa). The measurements were the mean daily ETa on monthly basis. The regression coefficients for these methods are shown in Table 11. The coefficient of determination (R^2) were 0.919, 0.912, 0.899, 0.912, 0.914 and 0.913 for $ETP_{(B-C)}$, $ETP_{(f)}$, $ETP_{(H-S)}$, $ETP_{(J-H)}$, $ETP_{(FAO)}$, and $ETP_{(H)}$, respectively. The high values of coefficients of determination (R^2) for the selected estimating method indicate that all these methods are good estimate of ETa.

4-7-3. Class-A Pan Evaporation .

Regression analysis were made for these estimating methods compared with screen class-A pan evaporation (Epan). The measurements were the mean daily Epan on monthly basis. The regression coefficients for those methods are shown in table 12. The coefficients of determination (R^2) were 0.994,

Table 10 . Regression equation of ETPlys values as a function of ETP_{B-C}, ETP_{f}, ETP_{H-S}, ETP_{J-H}, ETP_{FAO}, ETP_{H}, and their regression coefficient and standard error.

Estimating method	Intercept mm/day a	Slope b	Regression coefficient R^2	Standard Error S.E
ETP_{B-C}	1.533	0.455	0.840	0.560
ETP_{f}	1.271	0.494	0.839	0.562
ETP_{H-S}	1.522	0.555	0.831	0.578
ETP_{J-H}	1.430	0.564	0.803	0.623
ETP_{FAO}	1.420	0.600	0.798	0.631
ETP_{H}	1.218	0.641	0.793	0.645

$ETPlys = a + bETP_x$

Table 11. Regression equations of ETa values as a function of ETP_{B-C}, ETP_f, ETP_{H-S}, ETP_{J-H}, ETP_{FAO}, ETP_H, and their regression coefficient, and standard error.

Estimating method	Intercept mm/day a	Slope b	Regression coefficient R^2	Standard Error S.E
ETP_{B-C}	0.712	0.444	0.919	0.373
ETP_f	0.464	0.480	0.912	0.388
ETP_{H-S}	0.714	0.539	0.899	0.415
ETP_{J-H}	0.558	0.562	0.912	0.381
ETP_{FAO}	0.542	0.599	0.914	0.393
ETP_H	0.335	0.726	0.913	0.389

$ETa = a + bETP_x$

0.991, 0.942, 0.976, 0.986, and 0.970 for $ETP_{(B-C)}$, $ET_{(f)}$, $ETP_{(H-S)}$, $ETP_{(J-H)}$, $ETP_{(FAO)}$, and $ETP_{(H)}$ respectively. Standard error for the different methods (table 12) were 0.1728, 0.2106, 0.3001, 0.3404, 0.3973 and 0.5410 for $ETP_{(B-C)}$, $ETP_{(f)}$, $ETP_{(FAO)}$, $ETP_{(J-H)}$, $ETP_{(H)}$, and $ETP_{(H-S)}$, respectively. The improvement in (R^2) reduced the standard error significantly. All (R^2) values for the different methods indicated that they estimated Epan fairly well and the highest R^2 (0.991) was ETP_{B-C}. This is considered a new finding because all previous studies did not recommended ET_{B-C} method in this region.

4-7-4. Total Evapotranspiration.

Figure 16 and 17 show the cumulative evapotranspiration for ETa, ETPlys, Epan, $ETP_{(B-C)}$, $ETP_{(f)}$, $ETP_{(FAO)}$, $ETP_{(H)}$, $ETP_{(J-H)}$, and $ETP_{(H-S)}$ with the growing season. The total ETa was the lowest (1152.5mm), while $ETP_{(f)}$was the highest (2049.81 mm) which was very close to $ETP_{(B-C)}$ (2014.63 mm). Total $ETP_{(H)}$, ETPlys, and Epan values were 1420.97, 1476.21 and 1450.77mm, respectively. Total $ETP_{(J-H)}$ gave high values (1690.82 mm) because of using adjusted coefficients (Tx and C_T) which have increasing effect on ETP.

The regression equations for cumulative ET (ETcum) as estimated by the different methods as a function of growing season in months, and their correlation coefficients are shown in Table 13. The general form of the regression equation was as follows :

Table 12. Regression equations of Epan values as a function of ETP_{B-C}, ETP_f, ETP_{H-S}, ETP_{J-H}, ETP_{FAO}, ETP_H, and their regression coefficient and standard error.

Estimating method	Intercept mm/day a	Slope b	Regression coefficient R^2	Standard Error S.E
ETP_{B-C}	-0.401	0.793	0.994	0.173
ETP_f	-0.852	0.860	0.991	0.211
ETP_{H-S}	-0.326	0.947	0.942	0.541
ETP_{J-H}	-0.642	0.996	0.976	0.340
ETP_{FAO}	-0.698	1.068	0.986	0.300
ETP_H	-1.031	1.286	0.970	0.397

$ETpan = a + bETP_x$

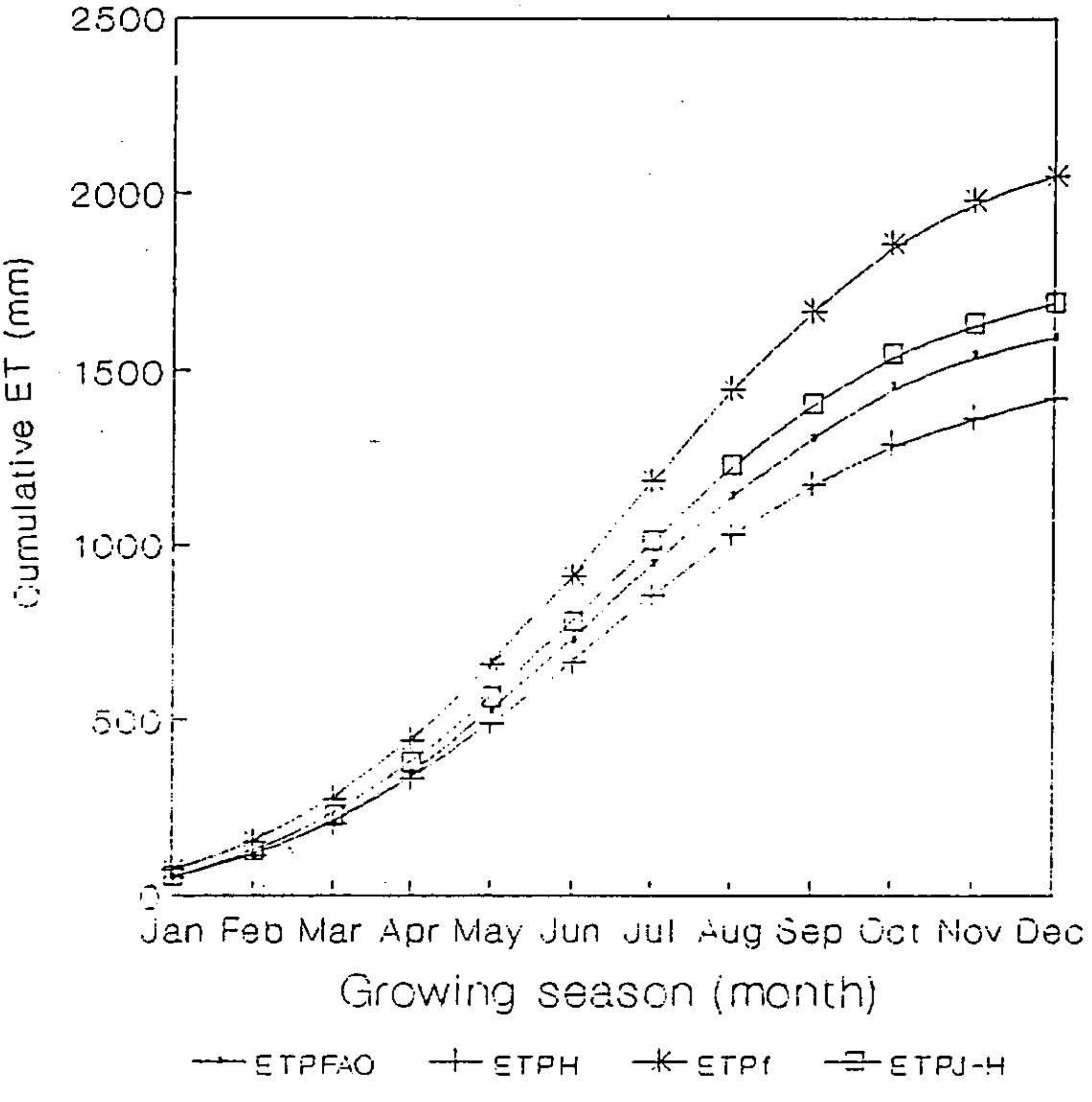


Figure (16) Cumulative ETPFAO, ETPH, ETPf , and ETa during the growing season, 1991.

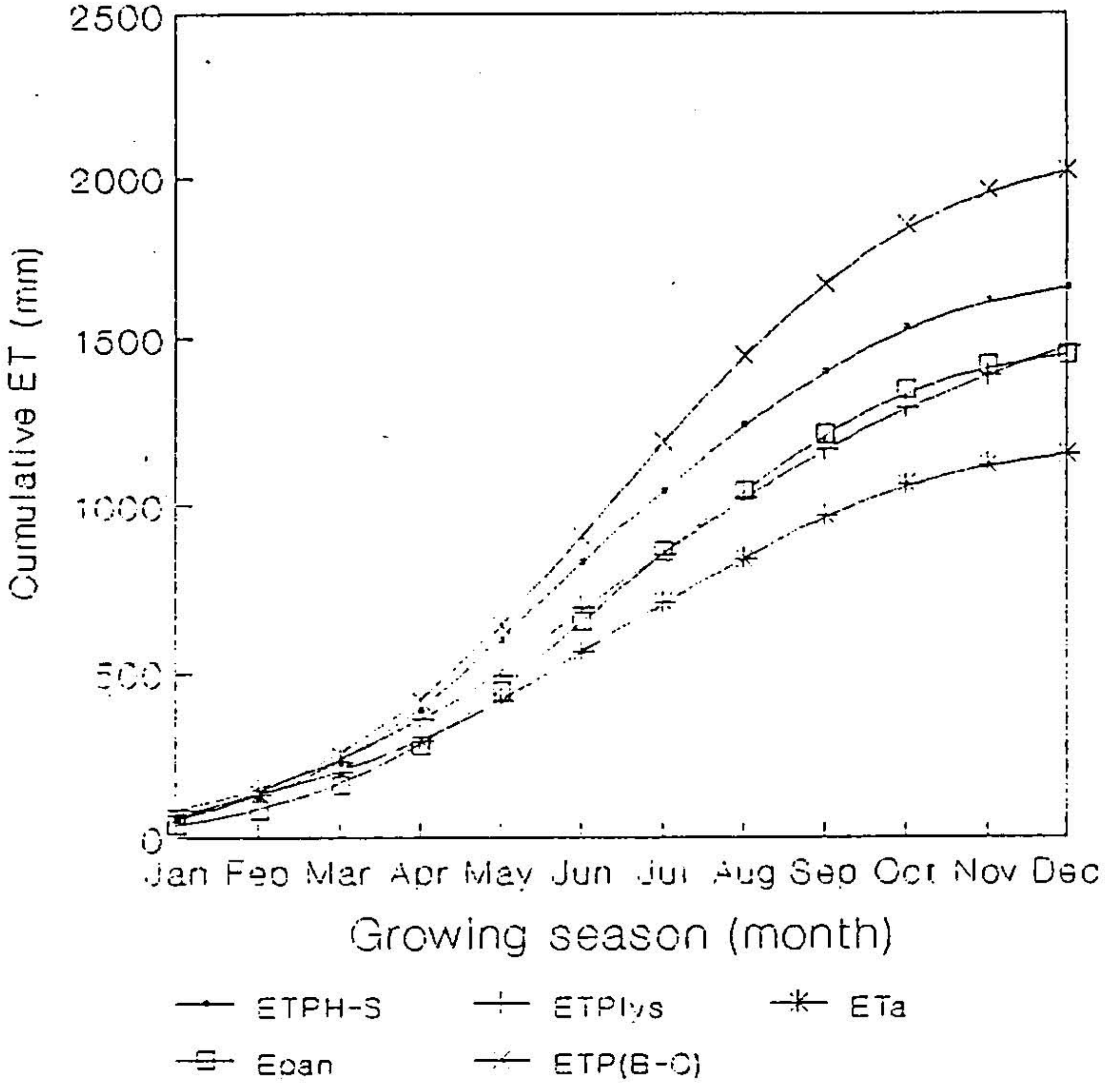


Figure (17) Cumulative ETPH-S, ETPlys, ETa, Epan, and ETPB-C during the growing season, 1991.

Table 13. Exponential equations for ET as estimated by the different methods as a function of growing season in month and their correlation coefficients.

Estimating method	a	b	correlation coefficient (R^2)
ETP_{FAO}	45.520	1.497	0.992 *
ETP_{H}	47.150	1.440	0.993 *
ETP_{J-H}	49.797	1.487	0.988 *
ETP_{f}	63.129	1.454	0.992 *
ETP_{J-H}	50.302	1.487	0.987 *
ETPlys	69.780	1.250	0.987 *
ETa	59.416	1.232	0.990 *
Epan	32.109	1.611	0.987 *
ETP_{B-C}	53.110	1.530	0.991 *

Ti = months in numerical order starting from January.
i = 1 through 12.
* = correlation coefficients are highly significant at 1 % level.

$$ETP_x = a(Ti)^b$$

$$ETcum = a\,(Ti)^{b}$$

where,

ETcum = cumulative ET ,mm

T_i = months in numerical order (starting from January), i = 1 through 12 .

4-7-5 **Measured ETa vs. ETPlys and Epan.**

Regression analyses were made for ETa of banana as a function of ETPlys on 10-days and on monthly basis. The regression equations obtained were as follows:

on 10-days basis

$$ETa = 0.610 + 0.633\ ETPlys, \quad R^2 = 0.576$$

$$ETPlys > 0$$

on monthly basis

$$ETa = -0.161 + 0.821\ ETPlys, \quad R^2 = 0.776$$

$$ETPlys > 0.2$$

The relationship between ETa and ETPlys obtained on monthly basis is shown in figure 18. Regression analyses were made between the means of average daily ETa and Epan on 10-days and on monthly basis. The regression equations obtained were as follows :

on 10-days basis.

$$ETa = 1.01 + 0.551\ Epan, \quad R^2 = 0.85$$

$$Epan > 0$$

on monthly basis.

$$ETa = 0.93 + 0.562\ Epan, \quad R^2 = 0.93$$

$$Epan > 0$$

Figure 19 shows the relationship between ETa and Epan on monthly basis. Results showed that Epan is a good estimate for ETa. Increasing the period from 10-days to monthly basis, R^2 values increased from 0.85 to 0.93.

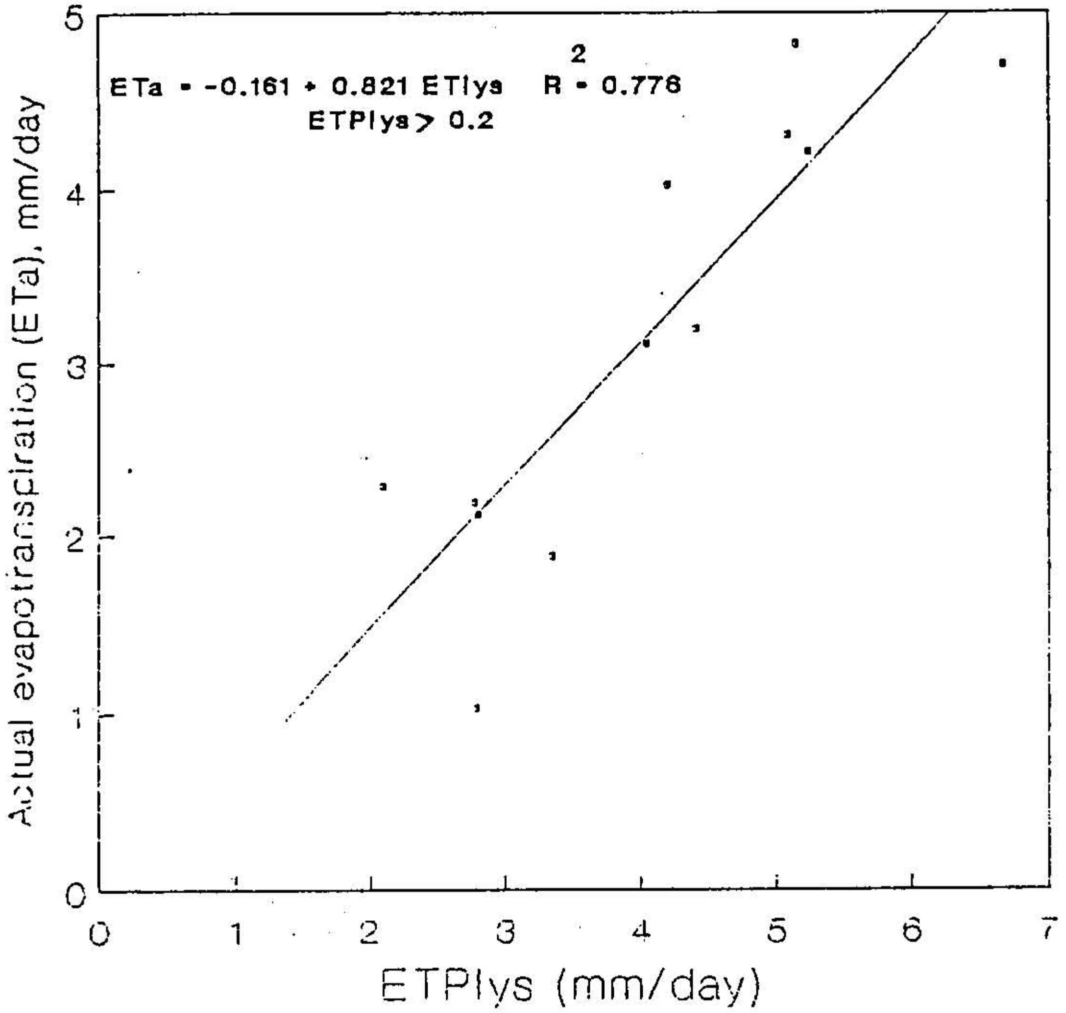


Figure (18) The relationship between average daily actual evapotranspiration measured by depletion method for mature banana (ETa) and average potential evapotranspiration by lysimetric method for grass (ETPlys) during the growing season.

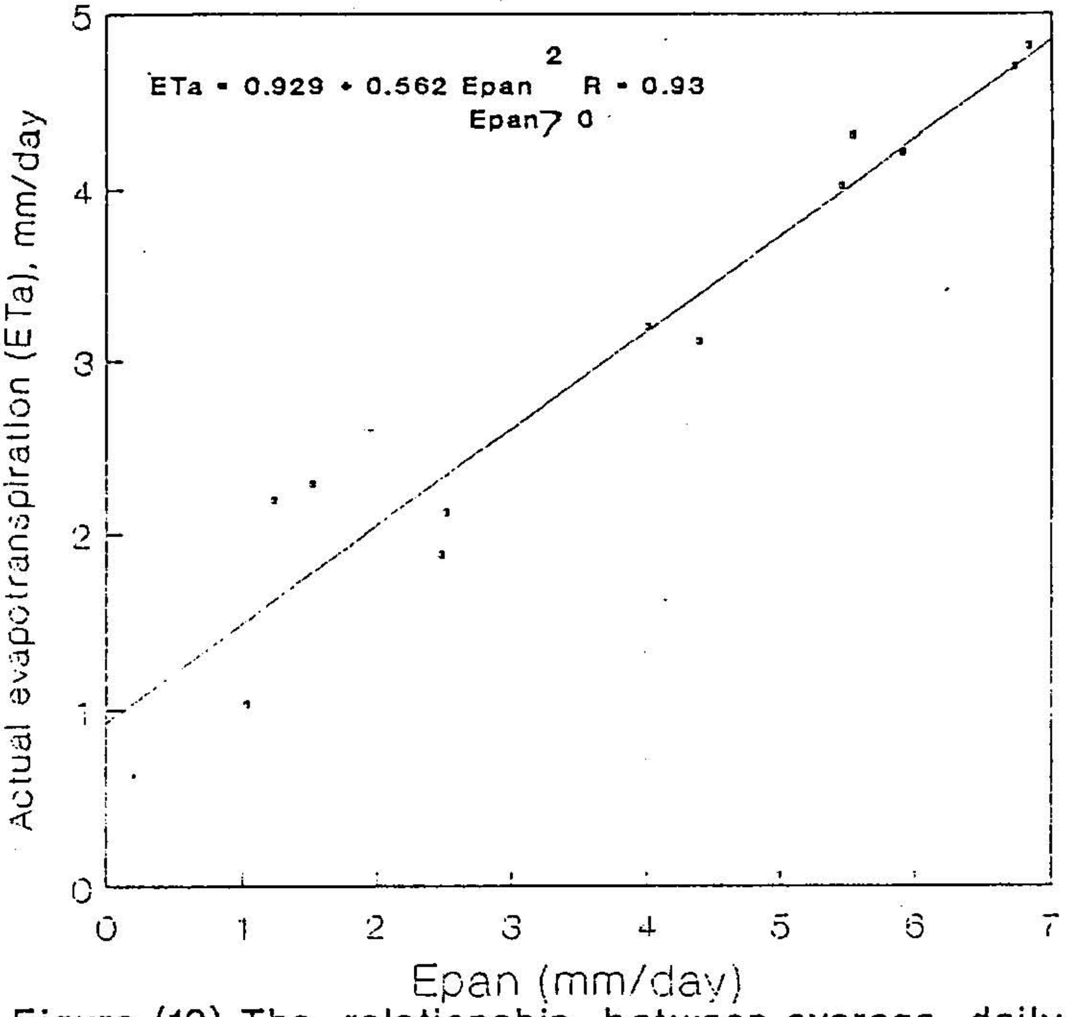


Figure (19) The relationship between average daily actual evapotranspiration measured by depletion method for mature banana (ETa) and average daily evaporation from class-A pan (Epan) during the growing season.

4-7-6. Measured potential evapotranspiration of grass by lysimetric method (ETPlys) vs. evaporation from class-A pan evaporation (Epan).

Regression equations and their correlation coefficients of ETPlys as a function of Epan on 10-days and monthly basis were developed. The regression equations obtained were as follows :

on 10-days basis.

$$ETPlys = 1.803 + 0.57\ Epan, \quad R^2 = 0.635$$

$$Epan > 0$$

on monthly basis.

$$ETPlys = 1.746 + 0.562\ Epan, \quad R^2 = 0.86$$

$$Epan > 0$$

Figure 20 shows the relationship between ETPlys and Epan on monthly basis. The correlation coefficient (R^2) indicated a significant correlation at 5% level. Increasing the period from 10-days to monthly basis, R^2 value increased from 0.635 to 0.86, respectively.

4-8. Effect of environmental factors on ETa, ETPlys and Epan.

4-8-1 Climatic factors effect on ETa.

Regression equations and their R^2 of ETa as a function of each of Tmin, Tmax, Tav , and Rs on 10-day and on monthly basis are shown in Table 14. On 10-days basis the highest R^2 (0.817) when ETa was expressed as a function of Tmax. This indicates that Tmax is the most effective climatic factor on ETa during these intervals. On monthly basis, the highest R^2 (0.871) was when ETa was expressed as a function of Rs; but

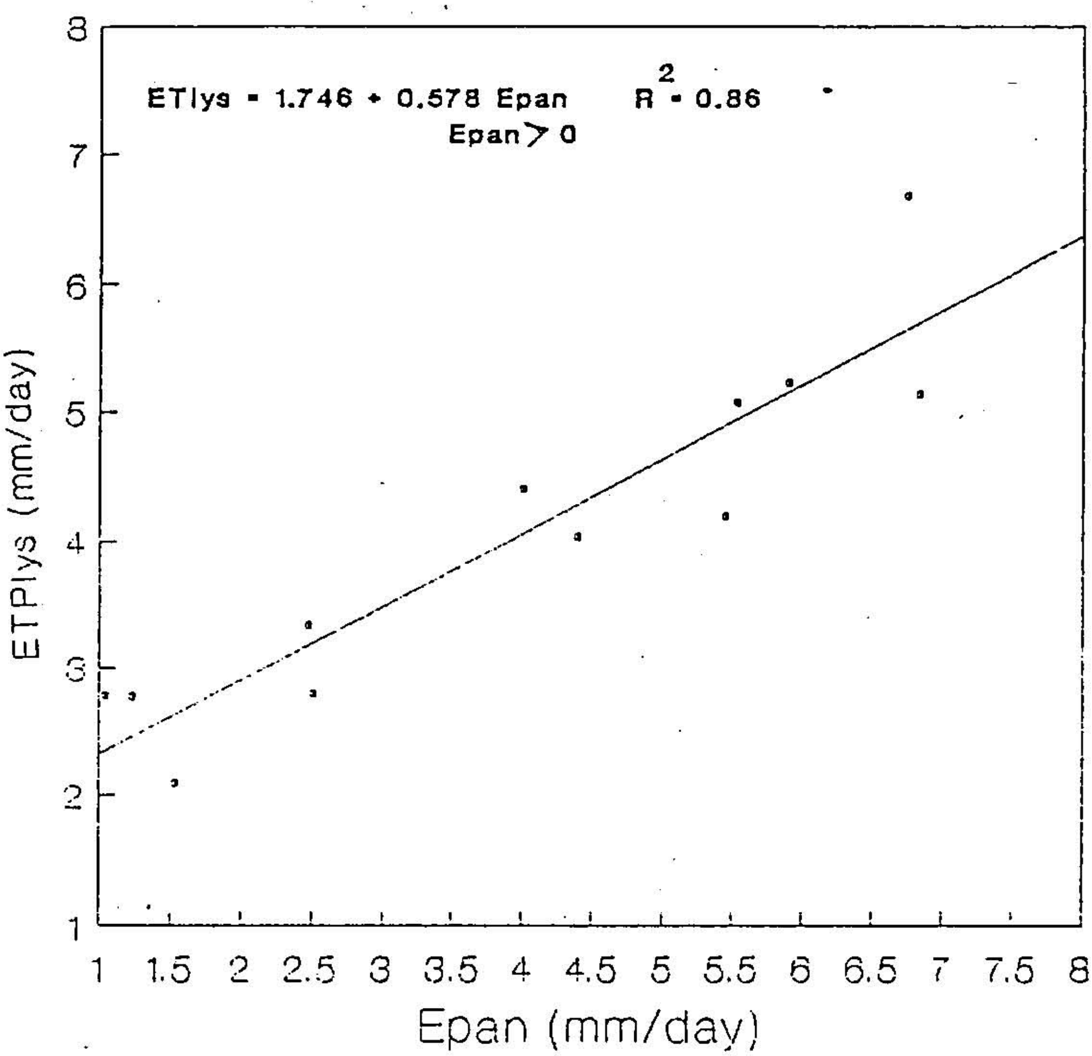


Figure (20) The relationship between average daily potential evapotranspiration by lysimetric method for grass (ETPlys) and average daily evaporation from class-A pan evaporation (Epan) during the growing season.

Table 14. Regression equations of ETa values as a function of selected climatic factors, and their regression coefficient and standard error.

Climatic factor	Intercept mm/day a	Slope b	Regression coefficient R^2	Standard Error S.E
		on 10-days basis		
Tmin	-1.695	0.183	0.754	0.639
Tmax	-1.234	0.147	0.817	0.551
Tav	-0.725	0.160	0.757	0.634
Rs	-0.364	0.540	0.760	0.630
		on monthly basis		
Tmin	-0.339	0.193	0.798	0.618
Tmax	-1.425	0.154	0.852	0.528
Tav	-0.977	0.173	0.834	0.559
Rs	-0.911	0.625	0.871	0.494

$$ETa = a + bx$$

was not significantly different from that of Tmax (R^2= 0.852). Therefore, it is recommended to use Tmax rather than using Rs to estimate ETa because Tmax can be measured easily.

4-8-2.The effect of climatic factors on ETPlys.

Regression equations and their R^2 of ETPlys as a function of each of Tmin, Tmax, Tav , and Rs on 10-days and on monthly basis are shown in table 15 and figure 21 and 22 Maximum temperature was the most effective climatic data which affected ETPlys on both 10-days and on monthly basis (R^2= 0.761 on monthly basis). The regression equations obtained were as follows :

on 10-days basis

$$ETlys = -0.392 + 0.148\ Tmax, \qquad R^2 = 0.576$$

$$Tmax > 3\ ^{o}C$$

on monthly basis

$$ETlys = -0.777 + 0.160\ Tmax, \qquad R^2 = 0.761$$

$$Tmax > 5\ ^{o}C$$

4-8-3. The effect of climatic factors on Epan.

Table 16 shows the effect of Tmin, Tmax, Tav , and Rs on Epan, and their regression coefficients for. The Tmax gave the best estimation of Epan on both 10-days and on monthly basis. The regression equations obtained are as follows:

on 10-days basis

$$Epan = -3.773 + 0.257\ Tmax, \qquad R^2 = 0.889$$

$$Tmax > 15\ ^{o}C$$

on monthly basis

$$Epan = -4.03 + 0.266\ Tmax, \qquad R^2 = 0.942$$

$$Tmax > 15\ ^{o}C$$

Table 15. Regression equation of ETPlys values as a function of selected climatic factors, and their regression coefficient and standard error.

Climatic factor	Intercept mm/day a	Slope b	Regression coefficient R^2	Standard Error S.E
		on 10-days basis		
Tmin	0.555	0.191	0.572	1.001
Tmax	-0.392	0.148	0.576	1.004
Tav	-0.020	0.167	0.573	1.007
Rs	0.655	0.517	0.486	1.106
		on monthly basis		
Tmin	0.325	0.198	0.716	0.793
Tmax	-0.777	0.158	0.761	0.728
Tav	-3.230	0.177	0.746	0.750
Rs	0.067	0.592	0.665	0.862

ETPlys = a + bx

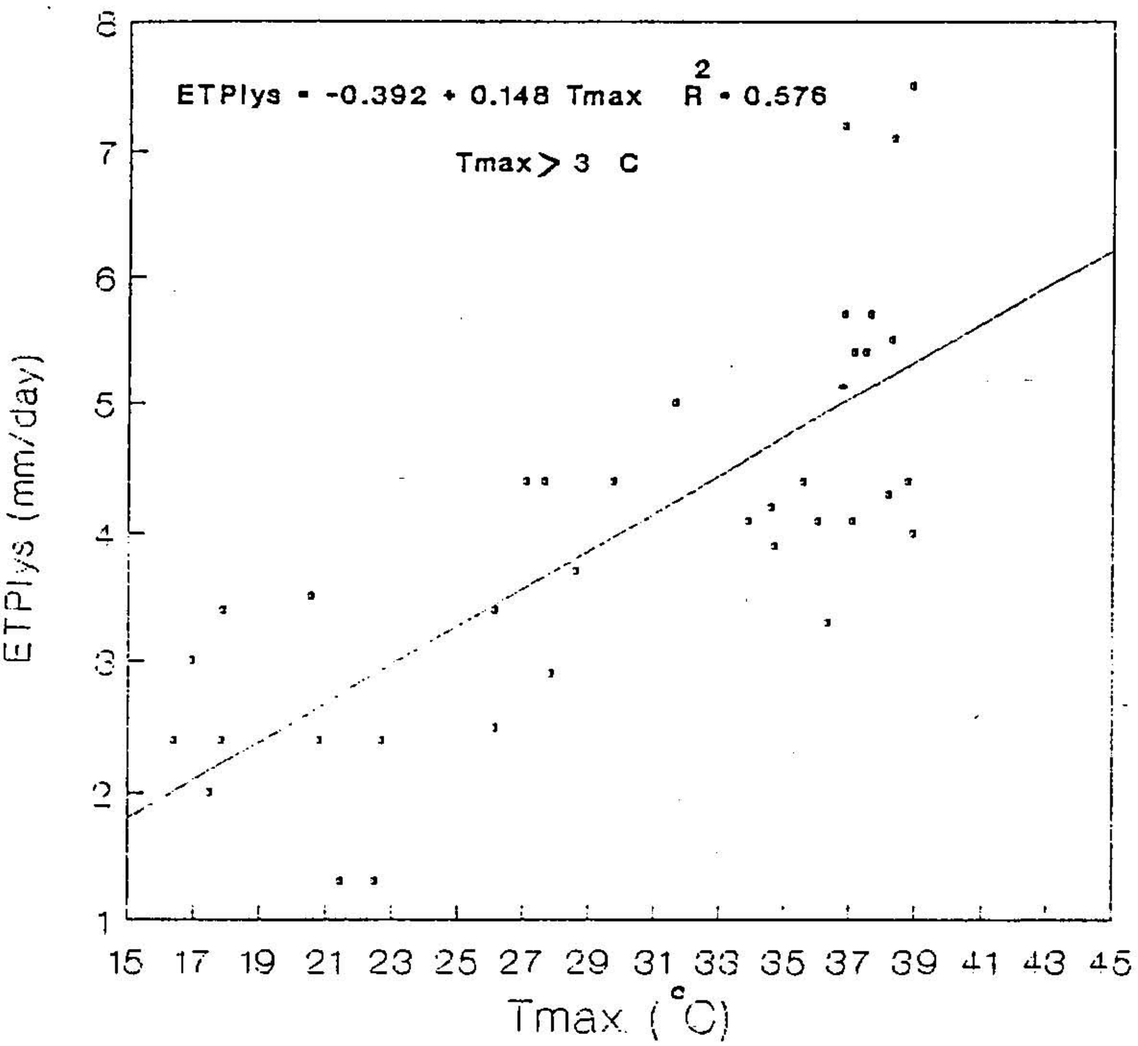


Figure (21) Relationship between potential evapotranspiration for grass by lysimetric method (ETPlys) and mean maximum temperature (Tmax°C) on 10-days basis.

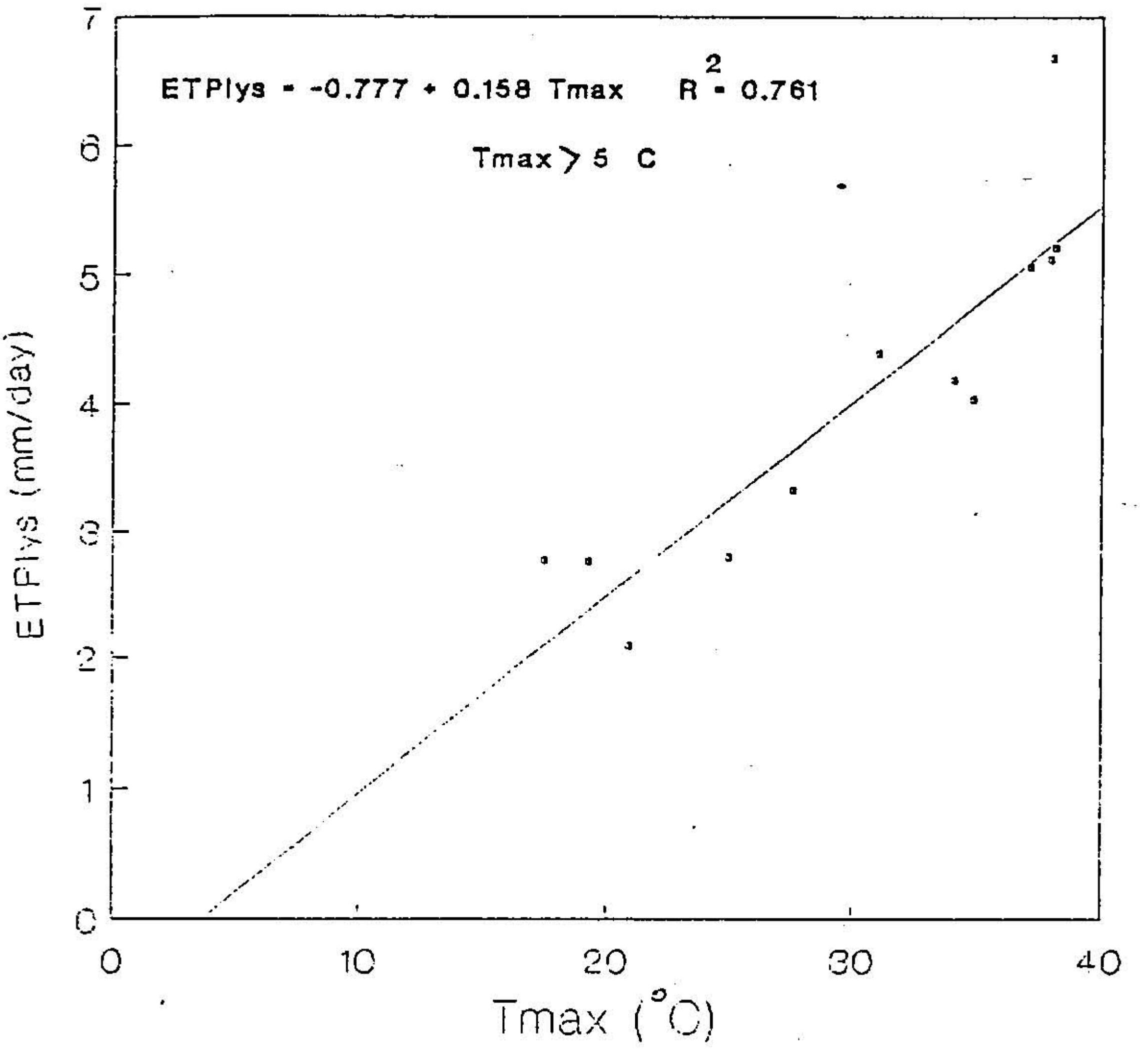


Figure (22) Relationship between potential evapotranspiration for grass by lysimetric method (ETPlys) and mean maximum temperature (Tmax °C) on monthly basis.

Table 16. Regression equation of Epan values as a function of selected climatic factors, and their regression coefficient and standard error.

Climatic factor	Intercept mm/day a	Slope b	Regression coefficient R^2	Standard Error S.E
	on 10-days basis			
Tmin	-2.045	0.327	0.857	0.814
Tmax	-3.773	0.257	0.889	0.720
Tav	-3.143	0.291	0.888	0.723
Rs	-2.230	0.948	0.835	0.877
	on monthly basis			
Tmin	-2.226	0.336	0.902	0.704
Tmax	-4.030	0.266	0.942	0.542
Tav	-3.290	0.300	0.932	0.550
Rs	-2.930	1.047	0.907	0.688

The highly significant correlation (R^2= 0.942) at 1% level indicates the excellent correlation between Epan and Tmax. Figure (23) and figure (24) show the relationship between Epan and Tmax on 10-day and on monthly basis, respectively.

4-8-4. The effect of mean maximum temperature (Tmax) and incident solar radiation in millimeter (Rs) on ETa, ETPlys and Epan.

Table 17. shows the multiregression coefficients for Tmax and Rs with respect to ETa, ETPlys, and Epan. The multiple correlation coefficients (R^2) for ETa were 0.84 and 0.913 on 10-days and monthly basis, respectively. Comparing R^2 obtained from using Tmax alone(R^2= 0.852) with R^2 obtained from using both Rs and Tmax (R^2= 0.913) showed higher correlation. The multilinear regression equations obtained were as follows :

on 10-days basis

$$ETa = -1.1525 + 0.0988Tmax + 0.209Rs, \quad R^2 = 0.84$$

$$Tmax > 12\ ^{o}C, \quad Rs > 0$$

on monthly basis

$$ETa = -1.399 + 0.0744Tmax + 0.3594Rs, \quad R^2 = 0.913$$

$$Tmax > 19\ ^{o}C, \quad Rs > 0$$

The multiple correlation coefficients (R^2) for ETlys were 0.58 and 0.769 on 10-days and monthly basis, respectively (table 17). Comparing R^2 obtained from using Tmax (R^2= 0.761) with R^2 obtained from using Tmax and Rs (R^2= 0.769). This indicates that a little improvement had occurred, which mean that it is not preferable to introduce

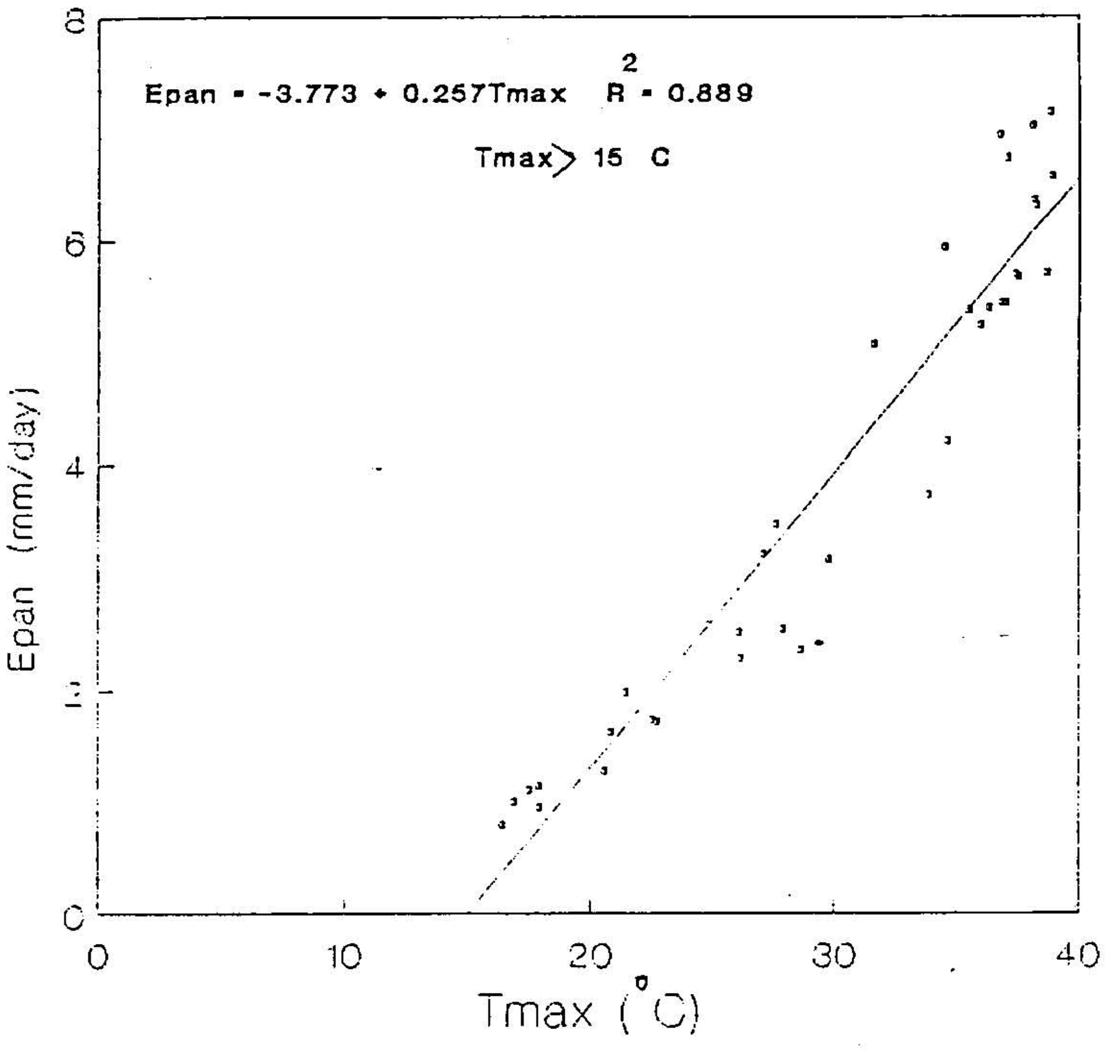


Figure (23) Relationship between evaporation from class-A pan (Epan) and mean maximum temperature (Tmax°C) on 10-days basis.

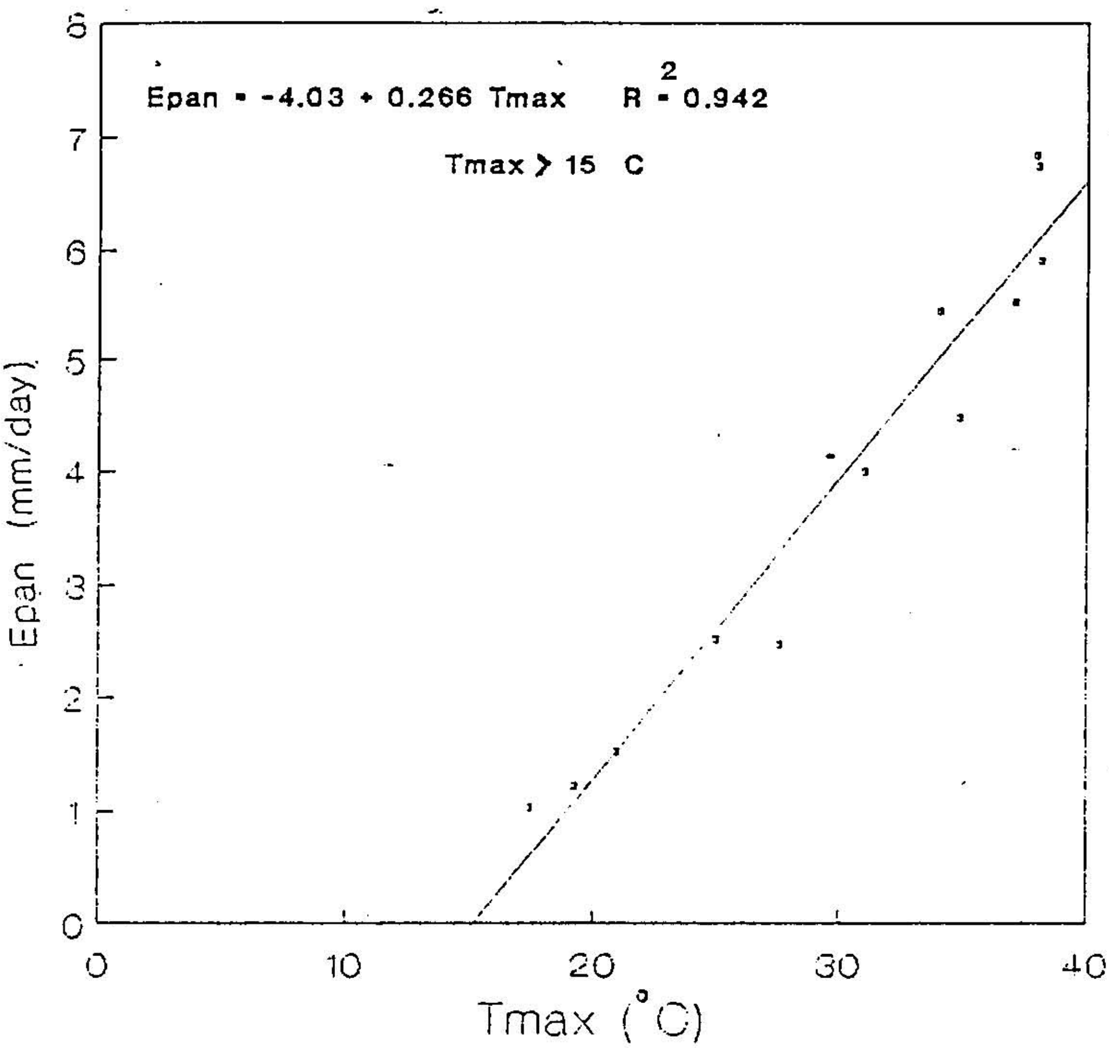


Figure (24) Relationship between evaporation from class-A pan (Epan) and mean maximum (Tmax°C) on monthly basis.

Table 17. Regression coefficients, determination coefficients (R^2), and Standard error (S.E) for three measured methods of evapotranspiration.

Measured methods	Intercept mm/day a	Tmax coeff. b	Rs coeff. c	R^2	S.E
		on 10-days basis			
ETa	-1.153	0.099	0.209	0.843	0.518
ETPlys	-0.355	0.127	0.093	0.580	1.015
Epan	-3.622	0.168	0.385	.0.919	0.621
		on monthly basis			
ETa	-1.400	0.074	0.360	0.913	0.428
ETPlys	-0.767	0.127	0.138	0.769	0.755
Epan	-3.996	0.162	0.468	0.980	0.333

$$ETx = a + bTmax + cRs$$

more than one environmental factor (Tmax) for estimating ETPlys.

The multilinear regression equations obtained for estimating Epan were as follows:

on 10-days basis

$$Epan = -3.6224 + 0.1681Tmax + 0.385Rs, \quad R^2 = 0.919$$

$$Tmax > 20\,^{o}C, \quad Rs > 0$$

on monthly basis

$$Epan = -3.996 + 0.162Tmax + 0.4685Rs, \quad R^2 = 0.98$$

$$Tmax > 25\,^{o}C, \quad Rs > 0$$

Comparing R^2 obtained from using Tmax ($R^2 = 0.907$) and Rs ($R^2 = 0.942$) separately with R^2 obtained from using both Rs and Tmax ($R^2 = 0.98$) indicated that good improvement had occurred. This mean that it is preferable to introduce more than one environmental factor for estimating Epan.

5.0 SUMMARY AND CONCLUSIONS.

A study was carried during 1991 growing season , at the University of Jordan Experimental Station located in the central Jordan Valley to determine water consumption and crop coefficients of mature banana plant.

The experiment was laid out in a completely randomized block design with four replications. The treatments were 50, 100, and 150 percent of weekly class-A pan evaporation (Epan). Each plot size was 9.0 x 9.0 m containing 9.0 banana trees. Three access tubes were installed in each plot at distance of 20cm, 60 cm, and 100 cm from the central tree in the same direction.

Actual water consumption of mature banana plant (ETa) was measured by depletion method using neutron scattering techniques for the different treatments. Potential ET by lysimeter using grass (ETPlys), Class-A pan evaporation (Epan), modified Blaney-Criddle (ETPB-C), FAO Blaney-Criddle (ETPFAO), f Blaney-Criddle factor(ETPf), Jensen-Haise (ETPJ-H), Hargreaves (ETPH), and Hargreaves-Samani method (ETPH-S) were estimated during the growing season in addition to their corresponding crop coefficients values (Kc). The plant parameters measured were ;pseudostem height, pseudostem girth, number of fingers per bunch, bunch weight, total yield, and water use efficiency.

Total amounts of water added were 1064.18, 1739.05, and 2413.92 mm for 50, 100, and 150% of Epan irrigation treatments respectively. The results showed the following:

1 - Total ETa of a mature banana plant for the 50, 100, and 150% of Epan were 941.06, 1152.5, and 1310.89 mm, respectively.

2 - The sucker height, sucker girth. number of fingers, and bunch weight of banana were significantly affected by water treatments to a certain limit.

3 - Irrigation of banana at 100% of Epan treatment gave optimum yield and WUE of 33.11 t/ha and 2.87 Kg/m^3, respectively. Reducing irrigation level to 50% of Epan reduced yield and WUE by 89.52% and 87.77%, respectively, while increasing irrigation level to 150% of Epan gave no significant increase in both values.

4 - Cumulative ETPlys, Epan, ETPH, ETPJ-H, ETPB-C, ETPFAO, ETPf and ETPH-S were 1476.21, 1450.77, 1420.97, 1690.82, 1595.95, 2014.63, 2049.81, and 1656.39 mm, respectively.

5 - Monthly Kc values for mature banana based on ETPlys ranged from o.36 to 1.1 during the growing season. Monthly Kc values based on the Epan and the six empirical methods ranged from 0.7 to 1.80 for Epan, from 0.57 to 1.34 for ETPH, from 0.58 to 1.25 for ETPH-S, from 0.54 to 1.26 for ETPJ-H, from 0.46 to 0.93 for ETPf, and From 0.62 to 1.36 for ETPFAO.

6 - The closest estimated ETP values to measure ETa and ETPlys values were the Epan followed by ETPB-C.

7 - The mean maximum temperature was found to be the best single climatic factor in predicting ETa, ETlys, and Epan.

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Table 1. Minimum tempreture (Tmin C), maximum temperature (Tmax C), minimum relative humidity (RHmin), maximum relative humidity (RHmax), wind speed two meters about the earth (U), solar radiation (RS), and rainfall (Rn) were taken from University Farm Metorological Station.

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/1/1991	12.1	20	35	44	60	87.6	
2	9	19.9	48	74	30	271.72	
3	10.5	21.1	55	80	73	260.9	11.4
4	14	19.1	62	86	20	261.47	
5	9	20.7	47	88	5	284.37	
6	8.3	20.4	46	88	40	248.8	
7	10.9	22.2	40	75	10	251.43	
8	12.1	19.8	56	90	7	152.58	
9	9	20.8	44	84	35	284.21	
10	8.9	21	38	80	15	287.09	
11	8	21.8	31	75	70	285.49	
12	10.6	23.9	24	45	320	290.44	4.8
13	11.2	15.9	58	86	9	83.74	
14	7	19.8	37	80	6	288.25	
15	8	20.3	42	70	10	289.94	
16	9.2	20.1	42	65	70	292.09	
17	9.2	21.5	35	64	15	288.91	
18	12.4	21.8	40	65	45	285.94	0.3
19	12	20.8	40	70	53	245.19	
20	9.1	21.7	42	75	27	213.4	
21	9	16	80	90	20	88.7	0.9
22	10	16.3	64	82	40	106.04	2.3
23	11.2	16.8	62	70	78	92.34	2.1
24	10.2	14	83	90	46	141.14	8.0
25	9	13.5	72	84	70	149.25	14.2
26	7.8	13.4	57	85	36	133.11	
27	3.8	15.8	44	90	18	295	
28	5.6	18.4	30	70	26	319.12	
29	8.6	18.72	32	50	39	325.07	13.6
30	10.1	17.7	70	92	42	123.96	16.9
31	12	19.5	70	76	110	109.81	8.7

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/2/1991	11.2	13.9	82	84	90	190.51	0.2
2	7	18.6	44	84	52	269.58	9.3
3	10.4	17.9	50	85	83	132.09	1.4
4	9.8	17	52	76	47	249.15	
5	5.9	19.2	44	70	68	271.29	
6	11	19.8	34	44	35	321.61	0.3
7	9.3	16.2	58	82	30	156.6	0.6
8	9	16.1	60	90	40	240.97	0.4
9	9.5	19.7	50	94	55	284.51	0.1
10	6.8	19.8	40	88	33	359.96	
11	9.8	22	34	84	69	370.2	
12	8.7	21.5	36	78	35	367.48	0.7
13	12.2	22.3	26	44	30	139.921	
14	18.1	22.6	30	62	38	374.54	
15	10.3	25.8	24	56	18	363.83	
16	16.2	22	40	70	40	205.74	
17	13	22	45	75	22	318.9	
18	9	21.9	40	90	69	386.74	
19	8.9	23.1	35	72	31	391.48	
20	10	23.4	30	68	100	384.98	
21	10	21.7	46	80	50	390.01	
22	12.8	27.8	30	50	25	405.85	
23	15	25	36	62	15	298.91	
24	11	24.8	32	79	73	404.97	
25	14	22.4	48	80	75	276.97	
26	13.9	19.2	60	84	25	261.4	4.0
27	9.2	18.7	74	73	60	171.38	7.0
28	10	20	52	94	13	378.64	

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/3/1991	9	22.8	36	92	10	296.36	
2	10.6	21.4	48	86	2	322.48	
3	9.1	22.8	40	80	83	406.76	
4	11.6	23.4	36	60	80	370.77	0.6
5	15	18.6	84	86	109	216.2	21.4
6	10.6	18.3	40	94	100	250.37	0.2
7	11.8	19.2	60	68	68	218.51	0.4
8	11.8	22	48	90	89	362.28	
9	15.9	22.7	50	68	59	353.75	
10	13.8	22.8	50	84	67	373.17	
11	14	24.6	36	58	40	351.75	
12	14.8	23	55	72	50	383.97	1.2
13	12	20.5	58	78	50	266.95	
14	10.8	24	36	84	30	439.04	
15	10	24.1	34	74	35	325.28	
16	13	28.8	26	60	24	373.37	
17	18	30.6	30	37	165	337.57	
18	22	31	35	65	98	410	
19	16	26.24	40	87	102	44.359	
20	16	28.1	42	74	52	225.93	
21	19.1	32.8	35	58	94	229.65	3.3
22	17.2	22.7	92	94	256	358.41	22.0
23	15.9	22.2	80	92	150	192.2	15.6
24	16	21	64	88	78	241.5	
25	13.9	24.3	50	92	36	430.58	
26	14.5	26.6	48	76	60	475.71	
27	15	28.5	40	78	80	461.18	
28	14.2	31	35	72	40	506.82	
29	17	31.2	42	70	48	490	
30	16.8	31	48	60	152	260.11	
31	15.3	26	42	63	90	441.86	

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/4/1991	14.4	28.3	40	82	60	274.01	
2	14.2	32.4	37	72	68	335.85	
3	20	28.4	38	56	70	274.06	
4	15	27	36	66	80	466.98	
5	13	25.4	42	72	43	410.47	
6	12	27.1	40	74	101	513.21	
7	13	33.9	28	68	103	456.39	
8	20.9	26.1	38	65	105	393.25	
9	14	22.8	54	74	130	513.41	4.9
10	14.8	24.6	34	63	100	215.64	1.7
11	15	22.8	48	90	50	384.11	
12	13	25.7	37	72	40	496.72	
13	12.2	28.1	33	70	75	535.31	
14	13.8	30	27	48	147	513.42	
15	20.3	33.4	31	40	70	497.44	
16	17	27.7	35	56	40	558.85	
17	14	25.9	38	64	80	528.6	
18	11.9	29	34	60	150	208.56	
19	13.8	36.5	22	50	100	562.76	
20	21	37.8	25	52	100	540.9	
21	19	34	60	70	50	481.43	
22	18	34.5	21	56	123	379	
23	23	38.7	22	36	85	478.02	
24	21.8	37	27	55	140	548.49	
25	20	34.1	25	62	260	450.9	
26	20	32.3	26	66	200	477.98	
27	20.4	32.4	28	60	140	398.03	
28	18.2	39.4	23	40	68	592.42	
29	23.5	39.2	27	44	72	312.48	
30	29.2	33.6	40	48	90	223.37	
31							

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/5/1991	22	23.2	68	90	126	401.78	
2	13	27.6	40	70	118	562.85	
3	13	30	33	67	140	485.69	
4	16	33.9	30	60	60	568.38	
5	16.8	37.9	22	52	76	601.71	
6	19	40.5	18	45	110	582.39	
7	21	38.8	21	40	117	544.94	
8	22	42	21	42	50	554.08	
9	25	34.2	32	54	110	402.26	
10	17.8	37.1	15	52	200	458.39	
11	23	38.8	20	52	70	408.8	
12	22.3	40	27	46	97	467.79	
13	25.2	40.4	24	44	100	386.23	
14	25.8	39.5	31	40	180	413.1	
15	28.4	39.2	33	50	200	343.32	
16	25	29.3	40	54	148	247.05	
17	20.7	30.6	36	63	120	406.07	
18	17.6	32.6	34	68	80	591.44	
19	19	36.2	22	60	131	504.33	
20	23.2	36.3	26	62	101	533.93	
21	23	29.7	35	52	115	545.81	
22	19.9	29	40	62	199	379.12	
23	17	31.3	35	66	70	594.1	
24	18	35.2	28	68	80	577.55	
25	22	36.6	32	66	96	601.5	
26	23	33.2	36	44	122	502.34	
27	20.7	27.9	46	52	117	249.11	
28	19.9	29.8	38	54	50	438.59	
29	16.1	31.6	40	60	117	595.42	
30	20.2	31.7	40	62	68	550.92	
31	18.7	31.4	42	64	135	600.52	

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/6/1991	18	32	40	64	150	527.77	
2	17	33.2	38	65	85	525.11	
3	19.1	36.7	25	56	180	534.36	
4	20.3	38.1	28	40	74	502.78	
5	23.6	39	30	45	116	428.43	
6	25	39	28	46	160	536.8	
7	21.8	39.2	40	66	75	537.02	
8	21.2	37.2	37	70	167	530.47	
9	22.8	38	34	74	120	412.47	
10	22	38.3	22	52	100	535.12	
11	23	34.2	38	50	130	532.91	
12	22.8	36.4	35	52	87	512.8	
13	23	37.4	34	50	98	533.35	
14	23	38.2	20	50	154	445.23	
15	24.4	37.2	26	52	146	526.37	
16	24	38.4	34	60	120	531.1	
17	23	39.5	28	68	180	513.26	
18	24	41	34	62	125	524.81	
19	25	41.1	32	82	135	509.21	
20	24.2	39.3	28	80	125	511.68	
21	24.8	40	30	60	119	516.41	
22	25.8	41.7	30	72	135	516.68	
23	26.4	40.7	38	68	154	459.79	
24	26.2	40	42	70	180	511.74	
25	26	38.9	40	72	114	518.1	
26	23.2	36.9	42	65	36	508.7	
27	25	37.8	42	60	57	368.4	
28	24.1	36.8	42	64	120	521.44	
29	24	38.2	36	68	124	518.82	
30	26	37.3	40	68	114	527.45	
31							

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
=======	======	======	======	======	======	======	======
1/7/1991	25	38.2	30	66	109	518.02	
2	25.8	38.1	40	64	153	531.13	
3	25	37.4	37	60	156	551.35	
4	24.2	38	36	60	131	539.66	
5	23.8	37.2	36	65	126	505.73	
6	24	34.4	46	70	89	550.67	
7	23	35.3	42	70	89	543.47	
8	25.3	35.4	44	70	100	536.7	
9	24	35.5	44	66	82	549.14	
10	25.1	38.4	42	75	114	540.34	
11	25	40	30	74	137	551.76	
12	24.8	39	28	60	160	553.61	
13	25	37.1	32	70	114	553.08	
14	25.9	38.2	32	80	90	566.62	
15	25	37.3	28	68	73	555.17	
16	25	38	33	50	115	496.13	
17	29.9	37.5	32	54	97	562.3	
18	23.8	38.8	32	55	86	526.02	
19	26	37	40	52	113	511.99	
20	24.8	38.6	31	60	136	547.33	
21	26.2	38.9	36	60	119	562.72	
22	27.2	39.8	40	64	103	551.05	
23	28	39.8	45	63	127	544.32	
24	26.4	39.4	34	68	88	553.97	
25	24	39	36	54	115	537.27	
26	27.6	38.4	42	62	77	534.7	
27	26.8	38.9	44	60	98	549.26	
28	26	40.7	27	64	87	551.04	
29	24.6	39.5	30	60	81	516.78	
30	26	37	34	56	88	545.4	
31	24	36.2	40	60	101	549.36	

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/8/1991	23.4	37	40	64	88	520.99	
2	25.8	39.6	33	70	115	513.67	
3	26.8	40.2	32	65	85	517.6	
4	28	38.8	46	75	109	514.73	
5	26.4	37.1	38	66	97	504.68	
6	24.8	37.6	42	62	102	431.67	
7	25.1	39.2	40	65	138	524.69	
8	25.5	40	33	64	107	470.94	
9	27.5	39.8	40	70	182	524.92	
10	27	37.9	38	70	67	517.51	
11	26	36	34	70	95	491.66	
12	27	39.1	33	68	112	506	
13	27.2	40.5	30	70	112	489.43	
14	27	40.6	30	59	104	498.96	
15	27.8	39.4	32	70	69	491.27	
16	24.2	36.8	42	65	100	515.91	
17	26.2	37.6	44	65	92	492.72	
18	27	37	46	71	76	473.72	
19	20.2	37.6	42	60	83	503.23	
20	26	37.6	42	66	75	495.42	
21	26	37.5	43	72	113	504.94	
22	26	387.1	40	64	76	515.23	
23	26.4	38.7	40	78	130	497.9	
24	26	38.1	42	68	102	490.12	
25	25	37.9	45	76	74	487.04	
26	26	38	40	74	84	492.71	
27	25	38.4	30	65	90	491.81	
28	25	37.5	39	70	88	486.43	
29	24	36.3	38	58	97	479.2	
30	24.8	36.3	44	68	115	489.22	
31	24	36.1	42	60	50	480.87	

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/9/1991	29	36.2	42	62	97	296.87	
2	24.9	35.4	35	60	91	309.87	
3	22.1	36	42	60	66	237.24	
4	23	38.1	31	70	116	379.7	
5	23.8	38	34	62	100	435	
6	24.2	35.9	38	65	85	478.55	
7	24	35.4	40	60	78	481.7	
8	22	35.6	42	63	137	261.79	
9	23	38.7	40	70	85	490.23	
10	25	38.7	30	70	115	371.8	
11	28	38.7	32	64	104	483.31	
12	25	37.2	40	62	121	484.79	
13	24	36.1	36	58	140	472.3	
14	24	38.4	38	65	96	450.36	
15	27	38.4	48	78	97	432.01	
16	28	37.7	42	70	128	491.57	
17	24	37.7	35	60	124	470.25	
18	25.2	36.8	36	68	90	383.79	
19	23	39.5	44	70	85	235.2	
20	24.8	33.8	50	66	65	448.15	
21	23	33.6	40	68	68	433.54	
22	20	34.1	40	65	98	450.17	
23	22.2	35	40	68	90	437.64	
24	24.2	36.4	42	73	126	435.53	
25	24.2	39.8	35	65	88	435.53	
26	23.2	40.7	22	58	40	441.6	
27	27.8	38.7	38	70	81	445.21	
28	20.2	37.7	30	64	92	491.57	
29	23.9	37.5	35	62	94	445.21	
30	23.1	37	30	65	91	433.42	
31							

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/10/199	24.1	39.5	32	66	105	366.11	
2	26.8	40.5	24	32	87	340.69	
3	29	39.5	27	42	112	330.93	
4	27.2	38.6	32	42	30	320.97	
5	24.8	36.8	36	70	108	376.62	
6	26.1	34.7	36	75	106	397.76	
7	21	33.2	37	56	81	405.68	
8	20.4	32.5	42	64	53	413.27	
9	20	32.1	45	70	90	393.57	
10	20.8	32.2	45	74	110	376.32	
11	18.5	33.8	28	62	64	384.71	
12	23	34.7	38	40	118	279.97	
13	28	35.9	40	44	115	245.98	
14	23	30.2	58	70	36	301.88	13.3
15	21	30.8	46	84	27	260.72	
16	21.2	32.2	40	76	47	335.63	
17	21.1	36	25	70	40	387.83	
18	20.8	31.2	21	56	57	371.32	
19	21	34.8	28	64	79	383.91	
20	24	38.6	27	50	125	350.12	
21	27.8	36.6	32	46	19	350.57	
22	25.2	36.4	28	50	35	363.05	
23	22	36.4	30	48	86	368.59	
24	25.1	36.1	34	54	33	454.83	
25	24.3	36.4	35	60	50	359.9	
26	23	36.2	28	55	100	367.27	
27	22.1	36.6	32	50	59	297.8	
28	19.4	28.6	36	58	75	360.91	
29	19.6	31.2	40	62	43	361.17	
30	20.8	31.6	33	60	30	287.36	
31	20	32.4	38	66	83	305.93	

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
1/11/199	18.9	33.1	14	65	60	162.45	
2	19	32.8	14	30	47	160.49	
3	21	28.1	40	34	137	132.09	7.0
4	18	23.9	42	68	96	178.46	2.3
5	17.1	24.2	46	83	15	215.4	
6	15	27.2	42	70	112	278.74	
7	17.2	28.7	36	64	22	332.24	
8	14.8	29.8	28	66	30	246	
9	15.4	29	30	70	19	319.89	
10	18	28.8	42	86	46	314.4	
11	16	26.8	44	88	46	325.94	
12	15.6	28.6	30	62	49	302.46	
13	16.7	27.4	40	62	30	266.31	
14	16.9	26.4	42	86	50	316.75	
15	15.4	27.5	36	75	54	308.78	
16	17.4	30.9	27	50	22	298.54	
17	17.5	28.6	42	70	14	307.44	
18	15	27.6	38	72	25	310.43	
19	14	26.9	42	82	40	272.63	
20	16.8	27.4	46	84	60	306.87	
21	17	27.6	40	75	75	299.06	
22	17	27.6	40	70	117	245.28	
23	17	28.2	38	60	63	295.72	
24	15	29.1	30	50	50	293.9	
25	15.8	29.8	28	48	17	292.56	
26	16	28	32	48	18	266.16	
27	18.2	27.3	54	74	32	265.54	
28	17.2	25.7	48	76	70	234.88	
29	15	17.4	82	94	116	120.51	24.2
30	13.2	20	60	90	109	157.85	26.0
31							

Table 1, cont' d

Date	Tmin C	Tmax C	RHmin %	RHmax %	U Km/hr	RS cal/cm.day	Rn mm
=======	======	======	======	======	======	======	======
1/12/199	13.2	16.8	76	90	88	264.33	10.0
2	11.1	12	74	90	131	252.9	12.7
3	14	15.3	84	85	132	263.5	30.0
4	13	17.4	82	82	64	206.6	5.5
5	13.1	18	64	62	14	183.3	
6	9.3	20.2	44	88	15	149.2	
7	13	20.4	56	80	7	81.85	
8	10.7	20.6	58	80	107	205.1	
9	15	19.2	42	44	143	193.5	
10	14	18.6	48	58	24	215.4	
11	12	20.2	44	70	127	170.3	12.9
12	13	15.4	66	70	84	240.1	7.5
13	12.6	13.6	68	82	170	236.3	3.8
14	8	17.4	54	94	121	164.2	
15	7.9	17.6	46	94	8	135.5	
16	7.2	17.8	48	90	24	102	
17	6.8	17	44	90	10	90.7	
18	5	16.9	35	84	8	79.4	0.2
19	9	15.7	56	92	20	166.9	
20	10	17.2	68	86	27	100.8	0.2
21	9	18	48	64	15	144.1	
22	7.4	19.6	42	94	19	78.5	
23	9.2	19.2	40	70	14	89.7	
24	9.2	16.2	58	80	66	2432	2.9
25	12	15.2	68	73	65	254.9	0.1
26	10.8	20.2	50	90	180	211.6	0.1
27	12.8	18.2	62	50	70	256.5	9.9
28	11.9	17	54	76	45	246.1	
29	8	18	43	90	9	80.2	
30	5.8	16.4	52	92	86	80.4	3.0
31	9.8	14.2	70	84	93	259.2	39.4

الصفحة غير موجودة من أصل المصدر

Sample of calulations

(a) Source Data

Location : University Experiment Station in Jordan valley.

Latitude : 32° north of the equator.

Elevation : 300 m below see level.

Period : April 1991. 30 days.

Mean air temperature = 24.08 °C.

Mean net solar radiation (Rs) = 7.45 mm/day.

Extraterrestrial radiation = 15 mm/day.

Mean minimumum relative humidity (RHmin) = 33.53 %.

1 . Haregreaves method (1977)

$ETH = (0.0135t + 0.24)\ Rs$

$= (0.0135 \times (24.08) + 0.24) \times 7.45$

$= 4.21$ mm/day

$Kc(H) = ETa/ETH$

$= 3.2/4.21$

$= 0.76$

2. Haregreaves - Samani method (ASCE, 1982)

$ETH\text{-}S = 0.0075 \times T^{o}F \times KT \times RA \times TD^{1/2}$

$RA = 15$ mm/day

$T^{o}F = 75.34\ ^{o}F$

$KT = 0.035\ (100 - RH)^{1/3}$

$= 0.035\ (100-47.45)^{1/3}$

$= 0.1311$

$TD = (Tmax - Tmin)$

$= (30.94 - 17.21)$

$= 13.73\ ^{o}C$

$= 24.71\ ^{o}F$

$ET = 0.0075 \times (75.34) \times (0.1311) \times (15) \times (24.71)^{1/2}$

$= 5.52$ mm/day

Kc(H-S) = ETa/ETH-S

= 3.2/5.52

= 0.58

3 . **Jensen - Haise method (1963), and Hansen et al. (1979)**

ETJ-H = C_T (T - Tx) Rs

Using temperature for August, the wormest month in the year to obtain constants.

Mean maximum temperature (TMc2) = 39.47 ^{o}C , e2 = 72.67

Mean minimum temperature (TMc1) = 23.17 ^{o}C , e1 = 28.41

$e = 1.3329 \exp^{[21.07 - 5336.0/(T + 273.1)]}$

$C_t = 1/(c1 + c2CH)$

CH = 50 mb/(e2 -e1)

= 50/(72.67 - 28.41)

= 1.1297

$c1 = 38 - (2\ ^{o}C \times EL\ (m)/305)$

$= 38 - (2 \times (-300)/305)$

= 39.97

$C_T = 1/(39.97 + 7.6 \times 1.1297)$, c2 =7.6

= 0.0206

Tx = -2.5 - 0.14(e2 - e1) - EL (m)/550

= -2.5 - 0.14(72.67-28.41) - (-300/550)

الصفحة غير موجودة من أصل المصدر

ETB-C = 5.52 x 0.98

= 5.42 mm/day

. FAO Blaney - Criddle formula, Doorenbos and Pruitt, 1977.

ETFAO = { a + b[p(0.46T + 8.13)]} { 1.0 + 0.1(Elv0/1000)}

Nratio = 2.0 (Rs/Ra) -0.5

= 2.0 (7.45/15) - 0.5

= 0.4933

a = 0.0043RHmin - Nratio - 1.41

= 0.0043(33.87) - 0.4933 - 1.41

= - 1.7576

b = 0.81917-0.0040922(Rhmin)+1.0705(Nratio) +0.056549(Uday) -

0.0059684(Rhmin)(Nratio) - 0.005967(Rhmin)(Uday)

Uday = U24/64.8

= 97.98/64.8

= 1.512

b = 0.81917-0.0040922(33.87) +1.0705(0.4933)+0.0065649(1.512)

-0.0059684(34.53)(0.4933) - 0.0005967(33.87)(1.512)

= 1.1776

p = 0.292 (Daily)

ETFAO = { -1.7576 + 1.1776 [0.292 (0.46(24.08) + 8.13)]} x

{1.0+0.1(- 300/1000)}

= 4.70 mm/day

Kc(FAO) = ETa/ETFAO

= 3.2/4.70

= 0.68

ملخص

تقدير الا ستهلاك المائي الفعلي ومعامل المحصول لنبات الموز كامل النمو في غور الا ردن الا وسط

يعاني الا ردن من محدوديه مصادره المائيه الا خذه بالا ضمحلال بشكل سريع ومستمر، نظرا للتزايد السكاني والتوسع في الصناعه وفي مجال الزراعه خاصة المروية منها. ويعتبر غور الا ردن من اهم واكثر المناطق اعتمادا على الري المستديم، لذا فأن حساب الا ستهلاك المائي الفعلي للمحاصيل بات امرا ضروريا للتحكم بكميات المياه المضافه خلال موسم النمو، مما يساهم بشكل فاعل في رفع وتحسين كفاءة استعمال المياه على الوجه الا مثل .

اجريت دراسه في محطة الجامعه الا ردنيه للبحوث الزراعيه الواقعه على بعد 45 كم الى الغرب من مدينة عمان و 25 كم الى الجنوب من محطة ديرعلا الزراعيه ، وقد هدفت الى قياس الا ستهلاك لمائي الفعلي لنبات الموز كامل النمو <u>paz</u> <u>cv.</u> <u>spps.</u> <u>Msa</u>. وتقدير معامل المحصول (Kc)، عن طريق ايجاد الا ستهلاك المائي الكامن المحسوب للنجيل بالا يسميتر والمقدر بالطرق غير المباشره الا خرى . أستخدمت طريقة الا ستنزاف الرطوبي للتربه بواسطة المجس النتروني في حساب الا ستهلاك المائي الفعلي الموسمي للموز (ETa) تحت ثلاث معاملات ري مختلفه وهي 50 ، 100 ، و 150٪ من قراءة حوض التبخر الا سبوعيه (Epan)، باتباع تصميم القطاعات الكامله المعشاه (CRBD) باربعة مكرارت لكل معامله باستعمال الري السطحي بالا حواض المربعه المستويه مساحة الحوض 81 م^2 ، تحتوي كل منها على تسع اشجار موز ، وتم كذلك دراسة استجابة نبات الموز لكميات المياه المضافه وتحديد دالة الا نتاج بالا ضافه الى مقارنة بعض الطرق غير المباشره مع الطرق المباشره في قياس الا ستهلاك المائي

دلت النتائج على ان الا ستهلاك المائي الموسمي الفعلي

للمون كامل النمو كالتالي: 941.06 ، 1152.5 و 1310.89 ملم لكل من 50 ، 100 ،و 150% من حوض التبخر على التوالي . وقد تبين ان نبات المون قد تاثر بشكل بالغ نتيجة لكميات المياه المضافه واشارت هذه النتائج الى ان ري المون بمستوى 100% من قراءة حوض التبخر الاسبوعيه حقق نتائج أفضل، أذ بلغ الانتاج 33.11 طن/هكتار وبلغت كفاءة استخدام المياه 2.878 كغم /م^{2}، وان خفض مستوى الري عند 50% من قراءة حوض التبخر سبب نقصا حادا بمقدار 89.52 % و 87.76 % من تلك القيم على التتابع، بينما رفع مستوى الري الى 150 % من قراءة الحوض لم يؤدي الى زياده ذات دلا له معنويه في الانتاج قدرت ب 12 % وسبب نقصا في كفاءة استعمال المياه مقداره 1.7 % .

تراوحت قيم معامل المحصول الشهري للمون بين 0.37 و 1.1 باستخدام اللايسميتر للنجيل كاستهلاك مائي كامن كذلك حدد ايضا المعدل الشهري لقيم معامل المون المتحصل عليها بالطرق السابقه . قدر الاستهلاك المائي الموسمي للنجيل (ETPlys) ، والتبخر من حوض التبخر (Epan) ، والمقدر بطريقة هارجريفز(ETPH) ، جنسن-هين (ETPJ-H) ، بلاني-كريدل المعدله (ETPB-C)، بلاني-كريدل بطريقة الفاو (ETPFAO)، معامل بلاني-كريدل (ETPf)، وهاريجريفز-سيماني (ETH-S) كالتالي : - 1476.21 ، 1450.77 ، 1420.97 ، 1690.82 ,2014.63 ,1595.95 2049.81 ، و 1656.39 ملم على التتابع

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أظهرت النتائج بان حوض التبخر يعتبر من افضل الطرق لتقدير الاستهلاك المائي الفعلي للمون والكامن للنجيل تليه طريقة بلاني-كريدل المعدله (ETPB-C). وأثبتت النتائج أيضا بأن درجه الحراره العليا (Tmax C) من أفضل العوامل الجويه المستعمله في تقدير الاستهلاك المائي الفعلي للمون والكامن للنجيل والتبخر من حوض التبخر.