EVAPOTRANSPIRATION MEASUREMENT AND MODELLING FOR BERMUDA GRASS, ALFALFA, CUCUMBER, AND TOMATO GROWN UNDER PROTECTED CULTIVATION IN THE CENTRAL JORDAN VALLEY.

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Submitted in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in
Agricultural Resources and Environment

Faculty of Graduate Studies
University of Jordan

March 2001

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DEDICATION

اهدي هذا العمل المتواضع

تخليدا لذكرى استاذي المرحوم

الدكتور

الفاضل ابراهيم غاوي عرفانا

بدوره الكبيرفي ابراز هذا البحث

الى حيز الوجود

ACKNOWLEDGEMENTS

I would like to express may great gratitude and appreciation to may advisor, Prof. Muhammad Shatanawi, for his guidance and encouragement throughout this study. Special thanks are to the co-advisor, Prof. Ahmad Abu-Awwad, for his great help and valuable advice.

Deep thanks and gratitude are extended to the committee members; Prof. Anwar Battikhi, Prof. Jamal Sawwan and Dr. Abdel Nabi Fardous, for their useful suggestions and comments.

Great thanks are extended to the National Center for Agricultural researches and Technology Transfer (NCARTT) for the financial support of this research. Special thanks are due to the general director of the NCARTT, Dr. Abdel Nabi Fardous, for his valuable and great help. Also deep appreciation are extended to the Regional Center of Deir-Alla for Agricultural researches and Technology Transfer for cooperation and help that facilitate this work. My thanks and great gratitude are due to my family, my friends and colleagues, specially Dr. Jumah Amayreh, Ali Gharaibh, M. Ayesh, Y. Alawenih, Wa'el Al-Shareef, M. Jitan, M. Meddaber. Dr. Dabbass, Mrs. Vicky, M. Abendih, Dr. Yasin Al-Zu'bi, Saleem Abu Al-Zaluff, all workers in the Deir-Alla Station and S. Asawdeh, for their help and encouragement.

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ABSTRACT

EVAPOTRANSPIRATION MEASUREMENT AND MODELLING FOR BERMUDA GRASS, ALFALFA, CUCUMBER, AND TOMATO GROWN UNDER PROTECTED CULTIVATION IN THE CENTRAL JORDAN VALLEY.

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This study was carried out during 1999/2000 growing season at the National Center of Deir-Alla for Agricultural Research and Technology Transfer in the Jordan Valley. The objectives of the study were: (a) To determine crop coefficient values for tomatoes (*Lycopersicon esculentum*) and cucumbers (*Cucumis sativus*) inside plastic houses using bermuda grass (*Cynodon dactylon*) and Hejazi alfalfa (*Medicago sativa*) as reference crops; and (b) To develop a model to estimate evapotranspiration for tomatoes, cucumbers, alfalfa and bermuda grass crops, using soil moisture content monitoring and meteorological data, under plastic house conditions. Measurements of evapotranspiration for four plastic house crops (grass, alfalfa, cucumber and tomato) were carried out by depletion method using Time Domain Reflectometry with Intelligent Micromodule Elements (TRIME) techniques.

The seasonal evapotranspiration inside the plastic houses were 327, 403, 356 and 214 mm for grass, alfalfa, tomato and cucumber, respectively, and the quantity of irrigation water applied were 428, 500, 429 and 275 mm, respectively. The Kc values according to growth stages for tomatoes based on grass reference crop inside plastic house ranged from 0.50 to 1.34, and based on alfalfa reference crop ranged from 0.31 to 0.91. While the Kc values for cucumbers ranged from 0.67 to 1.29 based on grass reference crop, and ranged from 0.46 to 0.81 based on alfalfa reference crop inside the plastic houses. The seasonal measured potential evapotranspiration values for grass and alfalfa crops inside the plastic houses were about 40% of their calculated values using Penman-Monteith equation in open field. Simple correlations between ET as dependent variable and Rn and VPD as indepent variables were proposed, based on the formulae of Penman-Monteith equation as ET = A*Rn + B*VPD. Average values for the leaf aerodynamic resistance (r_a) and leaf stomatal resistance (r_s) were derived using A and B coefficients. The r_a values were 428, 99, 555 and 1059 $s\ m^{-1}$, and the r_s values were 924, 448, 393, and 15 $s\ m^{-1}$ for plastic houses planted with grass, alfalfa, cucumber and tomato, respectively. The closest estimated ET to measured ET values inside the plastic houses were Penman-Monteith using the estimated r_a and r_s values, compared to the empirical methods. The results show also that the net solar radiation (Rn) was found to be the best single climatic factor in predicting evapotranspiration inside the plastic houses.

The linear relationships between the average weekly pan evaporation in open field and the evaporation from pans inside the plastic houses were derived. The evaporation from pans located inside alfalfa, grass, cucumber and tomato plastic houses were 0.50, 0.47, 0.22 and 0.31, respectively, of the evaporation from a pan located in open field. Weekly and monthly class-A pan coefficients (Kp) for the four plastic houses were derived and correlated with different climatic factors.

1- INTRODUCTION

Limited water resources in arid and semi-arid regions, such as Jordan, are considered the greatest challenge facing agricultural development in the country. In addition, high population growth rate in Jordan increases pressure on the available water resources.

About 70% of the available water resources in Jordan is allocated for irrigated agriculture. Decision-makers have to look for methods to reduce water consumption in this sector through developing appropriate management to improve water use efficiency. For these purposes, information about actual and potential plant water requirement under specified condition is necessary.

Irrigation scheduling aiming for maximum crop yield production is determined based on crop transpiration in the field with soil moisture maintained at an optimal condition. There are two ways to determine evapotranspiration (ET): a direct measurement through irrigation experiments which is cumbersome and time-consuming; and an indirect calculation using ET models which involves measurable climatic elements. Many farmers tend to over irrigate, as a safety guide to guarantee production. This is true when the price of water is inexpensive and the harmful effect of over irrigation is not counted. Wu and Kong (1996) conducted a computer simulation to evaluate the effect of over estimation or under estimation of ET from 0% to 60% for various uniformity of microirrigation expressed as coefficient of variation (CV) values (5%-30%), water costs, crop market price and cost of remediation. They showed that the determination of ET is significant to microirrigation scheduling and the degree of significance increases with the price of water and the cost of remediation.

Evapotranspiration is a necessary parameter for proper irrigation scheduling and for establishing the duties and the dimension of the irrigation system. It allows better water management, by adjusting the volume and frequency of irrigation to meet crop requirements depending on the soil characteristics. Furthermore, it is a crucial factor on which irrigation management decisions are based. Managing limited water supplies as well as designing and evaluating irrigation systems, are all dependent on ET data. Studies concerning ET for alfalfa and grass have special importance since alfalfa and grass are being used as reference crops for reference evapotranspiration estimation (Allen *et. al.*, 1994). Reference crop ET is the rate at which water will be evaporated from given plant and soil surfaces, with the surface specified, if water is readily available within the plant root zone, (Wright, 1996).

Tomato and cucumber are the main vegetable crops grown under plastic houses in Jordan. About 45% of the total plastic houses are located in the Jordan Valley (Ministry of Agriculture, 1998). It is believed that the total area under plastic houses will increase. The main objective of using plastic houses is to maximize the net return, by optimizing the environmental conditions.

Estimation of the crop coefficients (Kc) for vegetable crops and potential evapotranspiration for reference crops under plastic house conditions in Jordan are not available. There are limited studies available on this subject in the other countries (Abou-Hadid *et. al.*, 1994; El Moujabber *et. al.*, 1997). This lack of information implies that irrigation scheduling for these plants is quite empirical and could lead to great loss of irrigation water and low irrigation efficiencies.

This study was carried out at the Deir-Alla Experimental Station in the Jordan Valley with the following objectives: (1) To determine the crop coefficient values for tomatoes (*Lycopersicon esculentum*) and cucumbers (*Cucumis sativus*) grown inside plastic houses; and (2) To develop a model whereby the evapotranspiration of tomatoes, cucumber, bermuda grass (*Cynodon dactylon*) and alfalfa crops can be estimated using soil moisture content monitoring and meteorological data under plastic house condition.

2- LITERATURE REVIEW

Evapotranspiration (ET), the sum of evaporative losses of water from the soil and the crop, is one of the most basic components of the hydrological cycle. A major obstacle in evaluating water inventories and future demands is in determining crop water use and requirements. ET can either be measured or calculated. Under field conditions, accurate values of ET can be measured using soil water depletion and lysimetrs methods. However, due to its simplicity, the evaporation pan method has been one of the most widely used for determining ET. The use of the evaporation pan to predict crop water requirements is based on the assumption that it measures the integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface (Doorenbos and Pruitt, 1977). Based on the principle of the evaporation pan ($ET = K_{pan}E_{pan}$), a simple method was used by Agodzo *et al.* (1996) for measuring reference ET, using porous clay pot as an under-ground instrument in close association with the soil moisture reservoir. The most important advantage of the pot over the pan is that it is in close association with soil moisture and therefore reflects direct changes in soil moisture storage. This implies that the pot measurement provides an integration of the effects of soil; crop and climatic parameters.

The subject of evapotranspiration and crop water needs has been widely investigated by many researchers such as Doorenbos and Pruitt

الصفحة غير موجودة من أصل المصدر

or ET_r) is highly important to get a better estimate of the actual crop evapotranspiration (ET_c).

In recent years, Penman-Monteith equation has gained the interest of researchers, especially to predict crop ET in a one-step approach, without the use of the crop coefficient, as has been used previously. To do so, it is necessary to determine the crop aerodynamic (r_a) and bulk surface (r_s) resistances. Aerodynamic resistance (r_a) describes the resistance to the random turbulent transfer of vapour from the vegetation upward to the reference height and the corresponding vertical transfer of sensible heat from or toward the vegetation (Allen *et. al.*, 1994). The r_a term includes the effects of diffusive resistance through thin molecular layers along leaf surfaces, momentum transfer through pressure forces within the plant canopy, and turbulent transfer among canopy leaves and above the canopy. The r_s is defined as the stomatal resistance of the whole canopy and it can be computed from the resistance of vapour flow through individual stomata openings (r_L) and total leaf area of the vegetation (Allen *et. al.*, 1994).

The increase in plant water use was proportional to the decrease in the leaf-air temperature differences when the air temperature was more than the leaf temperature. Plants with a canopy temperature close to 24 °C showed an increase of 118% in water use when air temperature was increased from 8 to 18 °C and an increase of 33% when air temperature was increased from 18 to 24 °C (Al-Faraj *et. al.*, 1994). From the previous result, leaf temperature can be used in estimation of crop evapotranspiration under protected agriculture.

Water consumption by tomatoes during the 1990, 1991 and 1992 seasons at the Horticultural unit near Gainesville, Florda (USA) was equivalent to 75% of class-A pan evaporation. Evapotranspiration for the mentioned seasons were 318, 311 and 296 mm, respectively (Locascio and Smajstrla, 1996). They used class-A pan evaporation that located in the open field, which was good only for the local region.

While crop water consumption has been well investigated in the open fields and quantified for a wide range of weather conditions, limited data are available for greenhouse crops. Some studies have been conducted in the Jordan Valley on tomato water requirement and irrigation scheduling under the plastic houses using tensiometer and amount of water applied depending only on the soil factor. Battikhi *et. al.* (1985) found that increasing soil moisture tension significantly decreased irrigation amount. At 30, 50 and 70 cent bars treatments, applied water amounts were 854, 803, and 634 mm producing 197.4, 201.5, and 172.9 tons/ha of tomato yields, respectively. Suwwan *et al* (1985) showed that tomato plants consumed 490 mm of water inside the plastic house at the Jordan Valley. Shatanawi and others (1994) in the Irrigation Support Project for Asia and the Near east (ISPAN) report about irrigation management and water quality at the central Jordan Valley reported that the actual crop evapotranspiration for cucumbers and tomatoes under plastic houses was 328.4 and 500 mm, respectively, and found that farmers schedule their irrigation inside plastic houses similar to that in the open field. As a result of this scheduling, the water use efficiency was very low. All these experiments did not take into a count the climate, plant factors and crop coefficients in their ET_c measurements, which required potential evapotranspiration measurements under plastic house conditions.

Direct measurement of leaf water potential can indicate the relationship between the plant environment and the ability of the plant to absorb water and nutrients (Rudich *et al*, 1981). Water consumption of plants grown under plastic tunnels was different compared to those in open fields (Abou-Hadid et. al., 1988). They concluded that water requirement of vegetable crops grown under protected cultivation has to be re-estimated and irrigation management should be modified accordingly.

Eliades and Orphanos (1986) found that the best estimation of potential evapotranspiration (ETP) during the growing period of tomatoes grown in unheated greenhouses was by the following equation:

ETP = Epan out side the greenhouse x (0.26+0.008 x time as a percentage of the whole growing period). This equation was simple and applicable only in that region because it depended mainly on the climatic factors.

. Abou-Hadid *et. al.* (1994) concluded that it is possible to use pan evaporation to estimate water consumption of pepper under greenhouse conditions using the following equation: Epan plastic = Epan open x 0.70. They found that the water use efficiency was higher using the class A pan method than when the radiation method. This finding was due to the fact that pan evaporation differs from one region to another while radiation is almost constant throughout a large area. Kirda *et. al.* (1994) established a simple method for the estimation of evapotranspiration under greenhouse condition based on linear relationship between daily solar radiation and water evaporation from small beakers placed at various sites in the greenhouse. El Moujabber *et. al.* (1997) reported that Epan inside the greenhouse was equal to the half of the ETP calculated from climatic data of outside conditions.

Plant evapotranspiration modeling work has led to a form of the combination equation that closely approximates transpiration from various plants in a greenhouse environment (Al-Faraj *et. al.*, 1994; Fynn et. al., 1993; and Meyer et. al., 1993). The combination equation combines energy balance and heat/vapor transfer equations in modeling evapotranspiration. The incorporation of physical (environment) and physiological (plant) factors in the combination equation provides a sound conceptual framework for analyzing plant water and energy responses (Mankin *et al.*, 1998). The resulted models can be used for specific crops under greenhouse not under plastic houses conditions, because the plastic houses have completely deferent situation such as ventilation and heating. Leaf stomatal control of transpiration process should be considered in any realistic model that aims to estimate the ET for crops. (Maria *et al.* 1994)

Claudio and Kjelgraard (1996) utilized canopy surface resistance (r_c) in the Penman-Monteith model to estimate ET for potato and corn crops through back-calculated it by using lysimeter ET data, and the P-M model was shown to adequately estimate actual ET for the two crops in open field.

3- MATERIALS AND METHODS

3-1. Location

This research was conducted during the 1999/2000 growing season in four plastic houses (each 8.5 m wide and 53 m long) located at the National Center for Agricultural Research and Technology Transfer (NCARTT)/Deir-Alla Station in the Central Jordan Valley, at latitude of 32° N, 35°:30 East-longitude with an elevation of 224 meters below the sea level.

3-2. Data collection

3-2-1. Climatic data

3-2-1-1. Open field

Minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), wind velocity (U, Km day^{-1}), atmospheric pressure (P, kPa) and incident solar radiation (Rs, W m^{-2} day^{-1}) were collected from the meteorological Station of Deir-Alla.

3-2-1-2. Inside plastic houses

In each plastic house, daily Tmin (°C), Tmax (°C), RHmin (%), RHmax (%) and Rs were collected 30 cm above the crop level up to 2 meters and were recorded continuously every day by Thermo-hydrograph for the four crops planted in the plastic houses.

Incident solar radiation (Rs) inside each plastic house (the age of the plastic was two years) was estimated from outside Rs using SunScan readings in both sites at the same time. From these readings the inside to outside Rs ratios for the four plastic houses were determined. Net solar radiation (Rn) values were predicted also by using SunScan meter.

3-2-2. Soil data:

Undisturbed soil samples down to 90-cm depth were collected from sites representing the soil of the plastic houses at 0-15, 15-30, 30-45, 45-60 and 60-90 cm depths. Soil moisture characteristic curves for each soil layer were prepared using the ceramic plate extractor method (Richard, 1965), at 10, 30, 70, 100, 300, 500, 700, 1000 and 1500 kPa.

The following analyses were carried out for the collected soil samples: Textural class by pipette method (Day, 1965), apparent specific gravity by core method (Black, 1965), total nitrogen by Kjeldhal method (Bremner, 1965), available phosphorus by Olsen method (Olsen and Dean, 1965), available potassium by Ammonium acetate (CH_3.COONH4) extraction method (Pratt, 1965), electrical conductivity (EC) by conductivity Bridge in the soil water extraction (Bower and Wilcox, 1965), and soil reaction (pH) by pH-meter in soil water suspensions.

3-2-3. Crops data:

3-2-3-1. Grass and alfalfa (reference crops)

One plastic house was planted with Bermuda grass crop (*Cynodon dactylon*) which is suitable for hot climate at a seeding rate of 100 kg/ha. The other house was planted with Hejazi alfalfa crop (*Medicago sativa*) at a seeding rate of 50 kg/ha. Both crops were planted on July 15, 1999. Grass and alfalfa crops reached their full cover before the starting of this study. Fresh and dry weight (at 70 °C) of grass and alfalfa was measured after each plant cutting.

3-2-3-2.Tomato and cucumber

Jarash cucumber (*Cucumis sativus*) and Ghaleih tomato (*Lycopersicon esculentum*) seedlings were transplanted, each into one plastic house on 16 November, 1999 at a spacing of 40 cm between plants and 135 cm between rows (Fig. 1). Two rows of plants were planted per each trickle irrigation lateral (six laterals in each plastic house). The cucumber and tomato varieties were widely used by farmers in Jordan Valley for their high yield. Estimation of LAI for tomatoes, cucumbers, alfalfa and grass were performed at regular intervals (weekly) using the SunScan meter (Edmund *et. al* 1996). Plant height and plant yield of tomato and cucumber were also recorded.

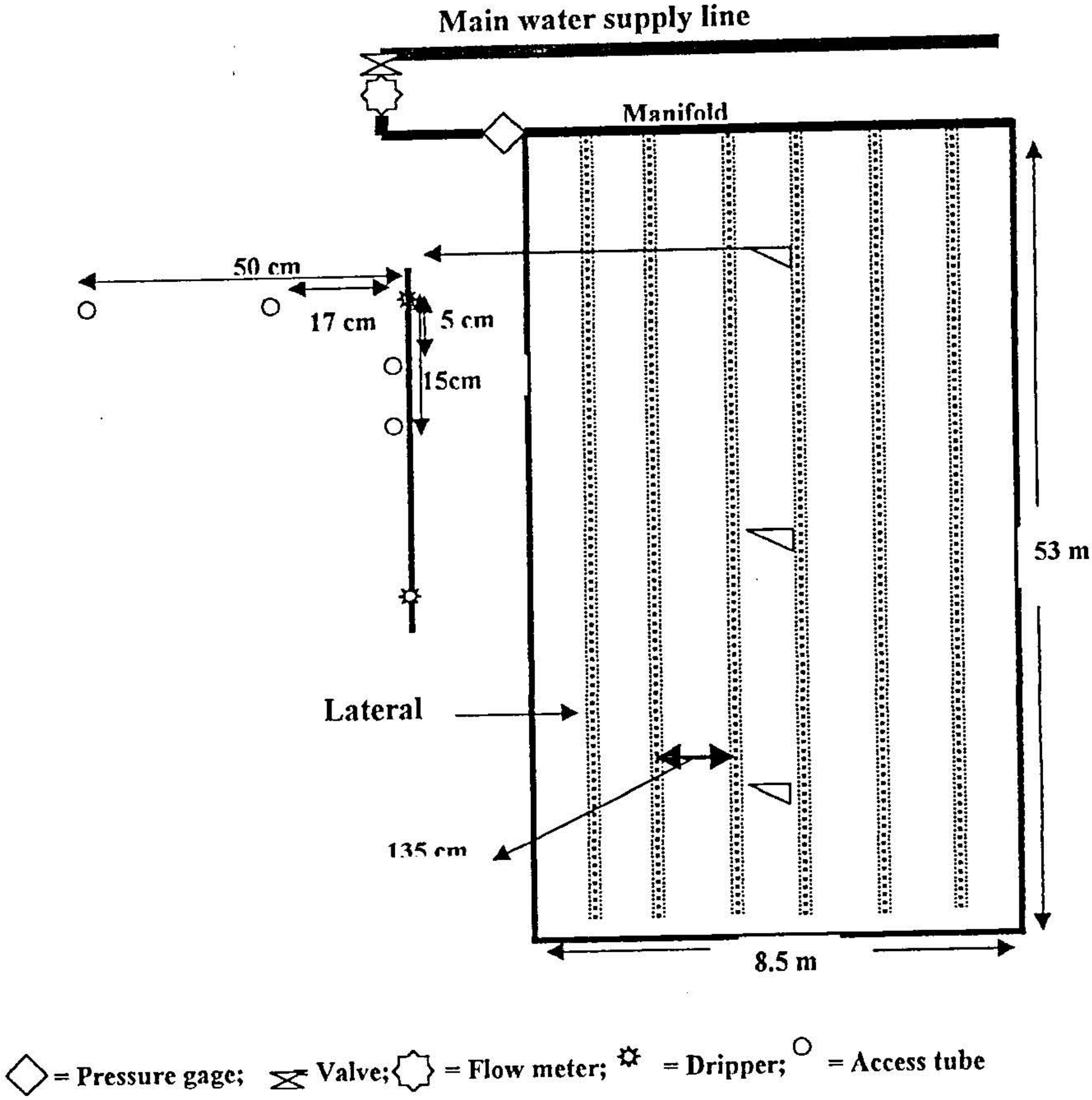

Figure 1. Drip irrigation system and access tubes locations inside the plastic houses planted with tomatoes and cucumbers.

3-2-4. Irrigation system

All crops inside the plastic houses were irrigated frequently (every 3 to 7 days depending on the average readings of two tensiometers installed at 15 and 30 cm soil depths) using a drip irrigation system to maintain soil moisture almost near the field capacity in the root zone (0.3-0.45 bar). Ammonium sulfate (21% N) fertilizers were applied through the irrigation system at each irrigation in a concentration of 50 ppm and were controlled using the Venturi fertegater. For grass and alfalfa, the spacing between drippers (GR) was 40 cm and spacing between laterals was 40 cm (Fig. 2). For tomato and cucumber crops, the spacing between drippers was 40 cm and 135 cm between laterals (Fig. 1). Inline drippers (GR) with 4l/hr discharge were used, the flow rate for each plastic houses were measured by flow meters. The amount of water applied for each irrigation event was measured using the following equations (Ayers and Westcot, 1985):

$$AW = \frac{ET}{(1 - LR) * E_a} \quad (1)$$

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad (2)$$

where;

AW = depth of applied water (mm)

ET = depth of crop water demand (mm)

LR = leaching requirement

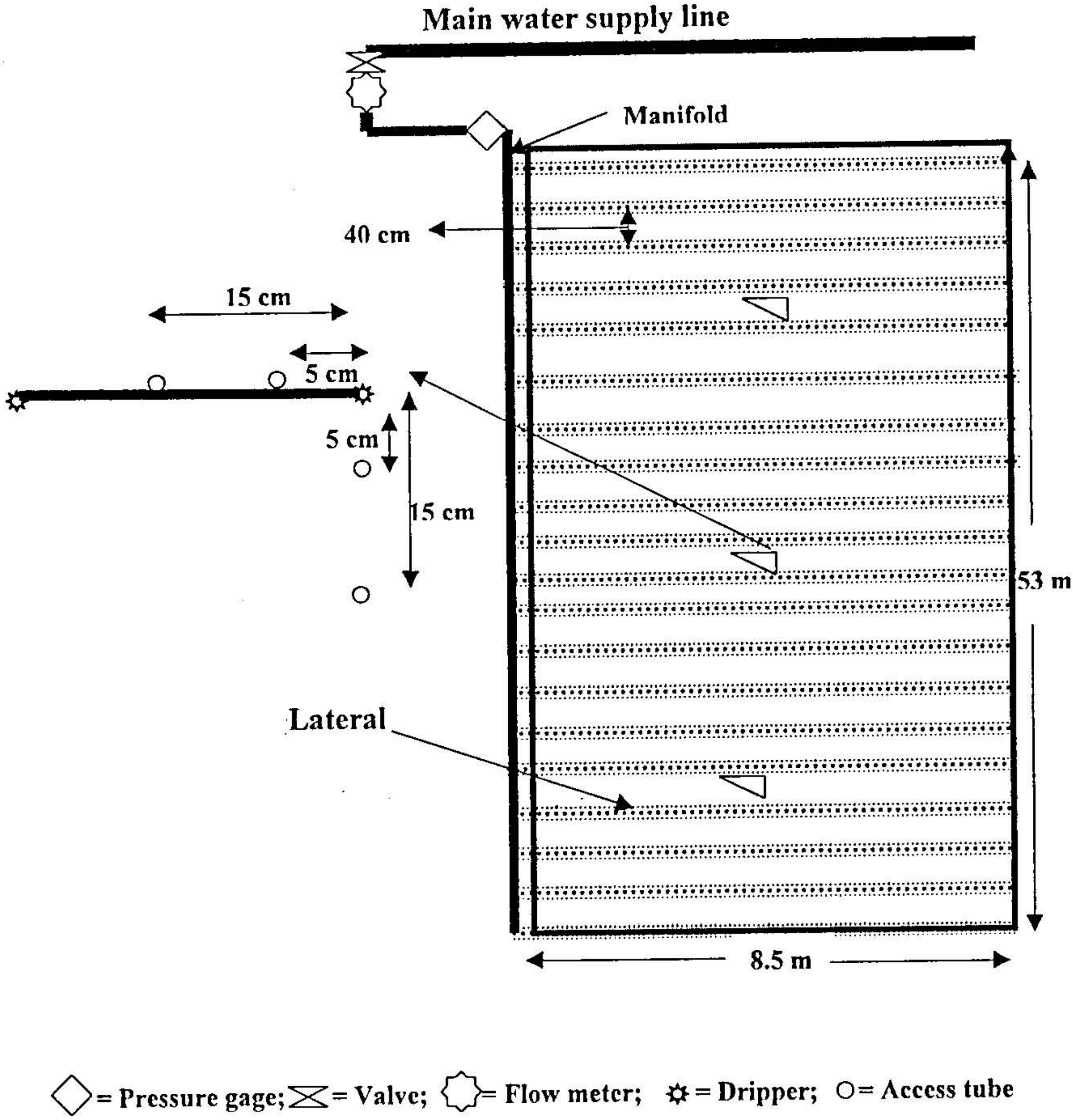

Figure 2. Drip irrigation system and access tubes locations inside the plastic houses planted with grass and alfalfa.

E_a = Irrigation application efficiency (assumed 90%)

EC_w = salinity of the applied irrigation water (dS/m), Abbendix1 Table 17

EC_e = salinity of soil saturation extract. (3 dS/m)

3-3. Evapotranspiration measurements

3-3-1. Depletion method:

The Time Domain Reflectometry with Intelligent Micromodule Elements (TRIME) technique (Stacheder *et. al.*, 1994) was used for measurement of soil moisture content through fiber glass access tubes at 7.5, 22.5, 37.5, 52.5, 67.5 and 82.5 cm to represent the whole 90 cm soil depth. For each crop (tomato and cucumber) 12-fiberglass access tubes, 100-cm long, were installed to represent three locations along the plastic house (at the begging, middle and at the end of the plastic house), four access tubes for each location. Two of the access tubes were installed between two drippers along the trickle line at distances 5 and 15 cm from dripper, and two access tubes between two drippers located in two adjacent lines (at distances 17 cm and 50 cm from the dripper) to monitor the moisture in two dimensions between the laterals and drippers (Fig. 1). For the grass and alfalfa, the same number of access tubes were used with fixed distances in the two directions from the dripper (5 and 15 cm) as shown in Fig. (2). Actual evapotranspiration (Eta) for each crop were measured using the depletion method. The values obtained by this method were the average of twelve measurements of the twelve access tubes. Soil moisture measurements were taken directly before and after 24 hours of each irrigation at the six depths of each access tube. Evapotranspiration rate was calculated according to the method developed by Claude (1959), and FAO (1977) using the following formula :

$$ET = \frac{\left|\sum_{i=1}^{n}(Pv_{1i} - Pv_{2i})S_i\right|}{\Delta t} \qquad (3)$$

Where,

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

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

Pv_{1i} and Pv_{2i} = volumetric moisture content after the first and before the second irrigation in the i-th layer, respectively,

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

t = the time interval between irrigation (days).

i = 1, 2, 3 ....6.

Evapotranspiration during the 24 hours after irrigation was considered as the average of ET values of before and after the 24 hours.

3-3-2. Penman-Monteith Model

3-3-2-1. Outside the plastic houses

All climatic data were collected from a nearby Deir-Alla station in which all sensors were located at 2 m above the ground surface and data were dayly recorded. The collected data were used to estimate the potential ET for grass and alfalfa crop under open field.

For estimating potential evapotranspiration for grass (ET_o) and for alfalfa (ET_r) as reference crops (Kg m^{-2} day^{-1}) in a nearby open field, Penman-Monteith model (Allen *et. al.*, 1994) was used which expressed as:

$$\lambda ET = \frac{\Delta(R_n - G) + 86.4\rho C_p \frac{(VPD)}{r_a}}{\Delta + \gamma\left[1 + \frac{r_s}{r_a}\right]} \quad (4)$$

Where,

R_n = net radiation (MJ m^{-2} day^{-1})

G = soil heat flux (MJ m^{-2} day^{-1})

VPD = (e_a-e_d) vapor pressure deficit of air at the reference height (kPa)

e_a = saturation vapor pressure at current air temperature (kPa)

e_d = saturation vapor pressure at the dew point (actual air vapor pressure , kPa)

Δ = slope of the saturation vapor pressure curve (kPa $^{\circ}C^{-1}$) at air temperature T_a ($^{\circ}$C)

ρ = density of air (Kg m^{-3})

C_p = specific heat of air (1.013 KJ kg^{-1} $^{\circ}C^{-1}$)

γ = Psychrometric constant (kPa $^{\circ}C^{-1}$)

r_a = aerodynamic resistance (s m^{-1}) to vapor transport

r_s = bulk surface resistance (s m^{-1}) to vapor transport

λET = latent heat flux of evaporation (MJ m^{-2} day^{-1})

λ = latent heat of vaporization (MJ kg^{-1})

86.4 = factor for conversion from KJ s^{-1} to MJ day^{-1}.

3-3-2-1. Calculation procedures

3-3-2-1-1-1. Crop canopy resistance (r_c):

$$r_c = \frac{r_L}{0.5LAI} = \frac{200}{LAI} \qquad \text{(Allen } et.\ al.\text{, 1989)} \qquad (5)$$

where:

r_L = average daily stomata resistance of a single leaf (s m^{-1}) = 100 for grass and alfalfa.

LAI = leaf area index

For clipped grass:

$$LAI = 24\ h_c \qquad \text{(Allen } et.\ al.\text{, 1989)} \qquad (6)$$

and for alfalfa:

$$LAI = 1.5 \ln(h_c) + 5.5 \qquad \text{(Allen } et.\ al.\text{, 1989)} \qquad (7)$$

where h_c = crop height (m).

= 0.12 m for grass and 0.50 m for alfalfa.

ET_o is defined as the rate of evapotranspiration from a hypothetical reference crop height of 0.12 m, a fixed crop canopy resistance of 70 s m^{-1}

and an albedo of 0.23, closely resembling the ET from an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water. ET_r is defined as the rate of evapotranspiration from a hypothetical reference crop height of 0.5 m, a fixed crop canopy resistance of 45 s m^{-1} and an albedo of 0.23, closely resembling the ET from an extensive surface of green alfalfa of uniform height, actively growing, completely shading the ground and with adequate water (Allen *et. al.*, 1994)

The crop canopy resistance (sm^{-1}) becomes:

$r_s = 70$ s m^{-1} for grass crop

$r_s = 45$ s m^{-1} for alfalfa crop

3-3-2-1-1-2. Aerodynamic resistance (r_a) (*Allen et. al.*, 1994)

The r_a values were estimated in open field using Equation (8).

$$r_a = \frac{\ln\left(\frac{z_m - d}{z_{om}}\right) \cdot \ln\left(\frac{z_h - d}{z_{oh}}\right)}{k^2 u_z} \quad (8)$$

r_a = aerodynamic resistance (s m^{-1})

z_m = height of wind-speed measurement (m)

z_h = height of temperature and humidity measurements (m)

k = Von Karman constant for turbulent diffusion (0.41)

u_z = wind-speed (m s^{-1}) measured at z_m height

d = zero plane displacement of wind profile (m)

$d = \frac{2}{3} h_c$ (Monteith, 1981)

z_{om} = roughness parameter for momentum (m),

$z_{om} = 0.123\ h_c$

z_{oh} = roughness parameter for heat and water vapor (m)

z_{oh} = $0.0123\ h_c$ (Brutsaert, 1975)

3-3-2-1-1-3. Net radiation (Rn)

The net radiation (Rn), the difference between the incoming net short-wave radiation and the outgoing net long wave radiation, is given by the following equation which is suitable for arid regions (*Allen et al.* 1998):

$$Rn = (1-\alpha)Rs - \sigma\left[\frac{T^4_{\max K} + T^4_{\min K}}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left[1.35\frac{Rs}{Rs_o} - 0.35\right] \quad (9)$$

where Rn = net solar radiation (MJ m^{-2} day^{-1}),

α = albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass and alfalfa references.

σ = Stefan-Boltzamann constant (4.903 x 10^{-9}MJ$K^{-4}$$m^{-2}$ day^{-1}),

$T_{max,K}$ = average daily maximum absolute temperature (K= C+273.16),

$T_{min,K}$ = average daily minimum absolute temperature (K= C+273.16),

e_a = actual vapour pressure (kPa),

Rs = measured solar radiation (MJ m^{-2} day^{-1}),

Rs_o = clear-sky radiation (MJ m^{-2} day^{-1}),

$$Rs_o = (0.75 + 2 \times 10^{-5} z)\, Ra \qquad (10)$$

Where

Ra = extraterrestrial radiation (MJ m^{-2} day^{-1}),

z = station elevation above sea level (m),

3-3-2-1-1-4. Mean saturation vapour pressure (e_s)

As saturation vapour pressure is related to air temperature, it can be calculated from the air temperature. The relationship is expressed by (Allen *et al.* 1998):

$$e_s = \frac{0.6108}{2}\left(\exp\left[\frac{17.27T_{max}}{T_{max}+237.3}\right] + \exp\left[\frac{17.27T_{min}}{T_{min}+237.3}\right]\right) \qquad (11)$$

where e_s= mean saturation vapour pressure,

T_{max} = maximum air temperature (°C),

T_{min} = minimum air temperature (°C),

exp[..] = 2.7183 (base of natural logarithm) raised to the power [..].

3-3-2-1-1-5. Slope of saturation vapour pressure curve (Δ)

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \qquad (12)$$

where Δ = slope of saturation vapour pressure curve at temperature T ($kPa\ ^oC^{-1}$),

T = air temperature (^oC)

3-3-2-1-1-6. Actual vapour pressure (e_a)

$$e_a = \frac{e^o(T_{min})\frac{RH_{max}}{100} + e^o(T_{max})\frac{RH_{min}}{100}}{2} \qquad (13)$$

where e_a= actual vapour pressure (kPa),

$e^o(T_{min})$ = saturation vapour pressure at daily minimum temperature (kPa),

$e^o(T_{max})$ = saturation vapour pressure at daily maximum temperature (kPa),

RH_{max} = maximum relative humidity (%),

RH_{min} = minimum relative humidity (%).

3-3-2-1-1-7 Atmospheric density (ρ)

$$\rho = 3.486\frac{P}{T_{kv}} \qquad (14)$$

$$T_{kv} = T_k\left(1 - 0.378\frac{e_d}{P}\right)^{-1} \qquad (15)$$

ρ = atmospheric density ($kg\ m^{-3}$),

P = atmospheric pressure at elevation z (kPa),

T_{kv} = virtual temperature (K),

T_k = absolute temperature (K) = 273+T (^oC),

e_d = vapour pressure at dew point (kPa).

3-3-2-1-1-8. Latent heat of vaporization (λ)

$\lambda = 2.501 - (2.361 \times 10^{-3})\, T$ (Harrison, 1963) (16)

where:

λ = latent heat of vaporization (MJ kg^{-3}),

T = air temperature (°C).

3-3-2-1-1-9. Psychrometric constant (γ)

$$\gamma = \frac{C_p P}{\varepsilon \lambda} \qquad (17)$$

where:

γ = psychrometric constant (kPa $°C^{-1}$),

P = atmospheric pressure (kPa),

λ = latent heat of vaporization ($MJkg^{-3}$),

C_p = specific heat at constant pressure, 1.013×10^{-3} (MJ kg^{-1} $°C^{-1}$),

ε = ratio molecular weight of water vapour / dry air = 0.622.

3-3-2-2. Inside the plastic house

3-3-2-2-1. Determination of resistance inside plastic houses

3-3-2-2-1-1. Aerodynamic resistance (r_a)

For open field crops, bulk aerodynamic resistance (r_a) is generally estimated from vertical wind-profile above the crop. This method is not applicable in greenhouses, where air speed is very low and free or mixed convection prevails. The leaf aerodynamic resistance, r_a was considered as roughly constant (200 s m^{-1}) in greenhouse conditions (Stanghellini, 1987).

3-3-2-2-1-2. Canopy surface resistance (r_s)

From Eq. 4, r_s values were predicted as:

$$r_s = r_a \frac{\Delta}{\gamma}\left(\frac{R_n + 84.6\rho c_p VPD/\Delta r_a}{\lambda ET} - 1\right) - r_a \qquad (18)$$

Determination of surface resistance (r_s) was accomplished in two steps: In the first step, r_s values were estimated from the P-M equation, using measurements of actual ET values, measured by depletion method using TRIME instrument. In the second step, from these r_s values, empirical relationships based on the model of Jarvis (1976) were established in order to predict r_s versus environmental factors which have a primary effect on r_s (Eq. 23).

The leaf stomatal resistance (r_L) is a function of leaf area index (*LAI*)

$$r_c = \frac{r_L}{0.5\,LAI} \qquad (19)$$

$$r_s = r_c + r_o \qquad (20)$$

$$r_o = bh_c \qquad (21)$$

Where r_c = crop canopy resistance,

r_o = an additional resistance primarily dependent on canopy structure.

h_c = crop height

b = slope of the regression, fitted through the origin.

The relationship between r_o and crop height (Eq. 21) was determined as illustrated in Fig. (3). Surface resistance r_s values were determined by P-M model (Eq. 18). Values of r_o were determined by subtracting r_c from r_s, where r_c is determined from (Eq. 19) using $r_L=r_{Lmin}$. The r_{Lmin} value was deduced from using the lowest weekly value obtained from (Eq. 18), assuming $r_s=r_{Lmin}$ (Maria et al. 1994). The resulting daily r_o and h_c were plotted and the fitted parameter of the linear relationship (Eq. 21) was determined for grass, alfalfa, tomato and cucumber. Since all crops will be well watered. The influence of soil and plant water potential on r_L were neglected. So, it can be written, using the multiplicative model of Jarvis (1976) as:

$$r_L = r_{L\,min} fVPD) \qquad (22)$$

Where fVPD is VPD-dependent adjustment factor. The factor fVPD was represented as a linear function of VPD (Jarvis, 1976):

$$f\text{VPD} = a + eVPD \qquad (23)$$

where a and e are linear regression coefficients.

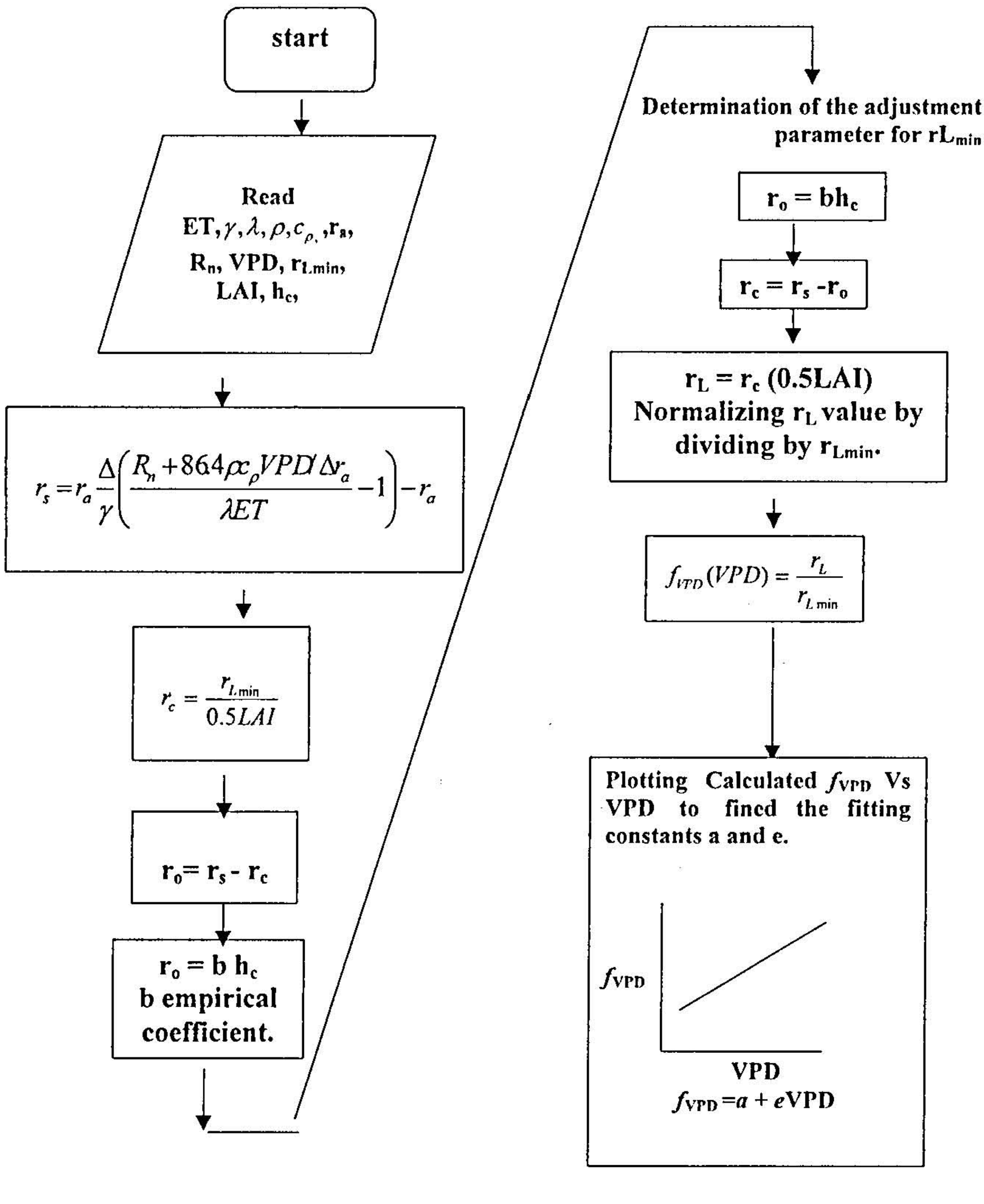

Figure 3. Flow chart of the model for the calculation of the fitting parameter b between r_o and h_c, and the determination of the adjustment factor for $r_{Lmin}(f_{VPD})$.

The adjustment factor *fVPD* for r_{Lmin} (Eq. 23) was determined on weekly basis : $r_c = r_s$(Eq.18) - r_o (Eq. 21). The r_L values were determined from Eq. (19) using the calculated r_c, and normalized using r_{Lmin} determined from Eq. (18) . Parameters for Eq. (23) were generated by first-order linear regression.

After determination of all fitted parameters, three forms of Eq. (4) were evaluated (Fig. 4); (1) where r_s consisted of r_c (Eq. 20) using r_{Lmin} (non-adjusted), and r_0 was ignored (r_0 = 0). (2) where r_s consisted of r_c (Eq.21) using r_L=r_{Lmin} (non-adjusted), and a crop-height dependent r_o (Eq. 21) and (3) where r_s consisted of r_c (Eq. 20), was determined with r_L based on adjusted values of r_{Lmin} (Eq. 22), and a crop-height dependent of r_o (Eq. 21).

3-3-2-2-3. Evapotranspiration modeling using Penman-Monteith equation.

For plastic house crops, the formula used for evapotranspiration (ET) prediction is based on simple linear correlation between ET and solar radiation, Rs (Stanhill and Scholte, 1974)

$$ET = A * Kc * Rs + B \quad (24)$$

Where Kc is crop coefficient depends on the crop development stage. A and B are two coefficients determined by statistical adjustment. This relation

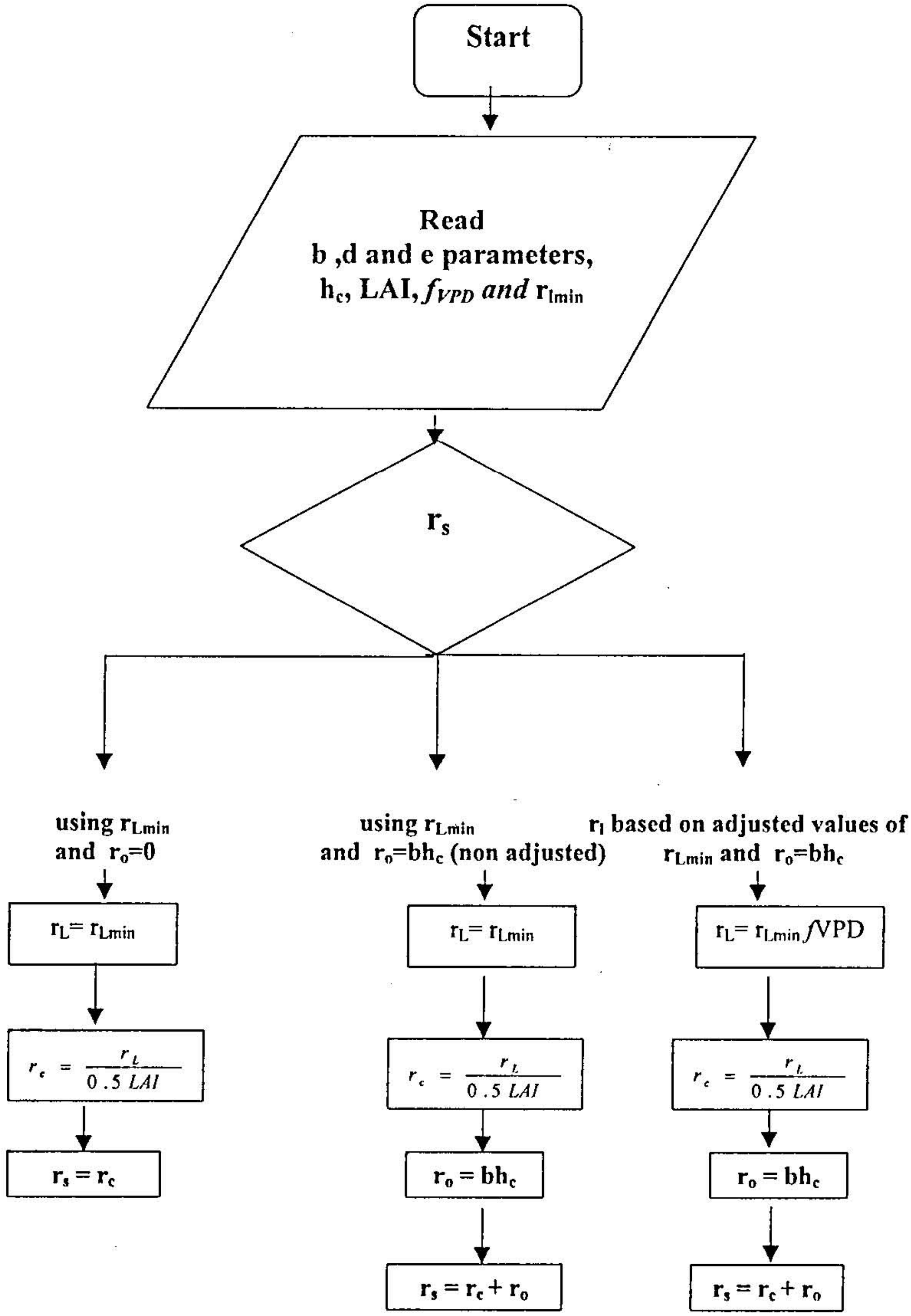

Figure 4. Flow chart of a method to evaluate three forms of r_s calculations of grass, alfalfa, cucumbers and tomatoes.

presents several drawbacks such as single climatic factor dependent and needed Kc values which almost unavailable for plastic houses.

The influence of vapour pressure deficit (VPD) and net radiation (Rn) were considered in the following relationship a simplified model developed by Maria *et al* (1994), which derived from the formulae of Penman-Monteith equation:

:

$$\mathrm{ET} = A * \mathrm{Rn} + B * VPD \qquad (25)$$

Where ET is the crop evapotranspiration rate (kg m^{-2} day^{-1}), Rn is inside net solar radiation (converted in equivalent MJ m^{-2} day^{-1}), VPD is inside air vapour pressure deficit (kPa), A and B are values of model parameters (A in MJ^{-1} kg , B *in* kg m^{-2} day^{-1} kPa^{-1}). Maria *et al* (1994) assumed that Rs was equal to Rn, while in this study the calculated Rn values were used.

If we assume that in plastic house conditions soil heat flux density (G) is equal to zero, then Penman-Monteith equation (4) can be written as:

$$\lambda ET = \frac{\Delta R_n}{\Delta + \gamma\left[1 + \frac{r_s}{r_a}\right]} + \frac{86.4\rho C_p \frac{(VPD)}{r_a}}{\Delta + \gamma\left[1 + \frac{r_s}{r_a}\right]} \qquad (26)$$

The coefficients A and B can be considered as estimations of the following terms appearing in the Penman-Monteith equation:

$$A = \frac{\Delta}{\lambda(\Delta + \gamma\left[1 + \frac{r_s}{r_a}\right])} \qquad (27a)$$

$$B = \frac{86.4 \rho Cp \frac{1}{r_a}}{\lambda (\Delta + \gamma \left[1 + \frac{r_s}{r_a} \right])} \quad (27b)$$

A corresponds to the coefficient of the 'radiative' component, and *B* to the 'advective' component.

3-3-2-2-3.1 Determination of aerodynamic resistance (r_a) and canopy surface resistance (r_s) inside plastic houses.

As the leaf aerodynamic resistance, r_a can be considered as roughly constant in greenhouse conditions (Stanghinelli, 1987), r_a and r_s values for grass, alfalfa, cucumber and tomato were estimated by determination of *A* and *B* values from statistical regression between weekly evapotranspiration rate using depletion method on one hand, and Rn and VPD on the other.

3-3-3. Pan evaporation:

Four Class-A pans were used inside the plastic houses. One pan was located in the center of each plastic house. One pan was located in a nearby open field.

3-3-3-1. Class A pan coefficient (Kp) in open field

In open field conditions the ETpan using grass as reference crop was calculated for a certain period, by multiplying the evaporation from a pan (Epan) by the pan coefficient (Kp) in that period. The Kp values in open field were estimated using the following equation (Allen *et. al.*, 1998):

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3-3-4. Hargreaves method

Hargreaves (1977) developed an equation for estimating ET as follows:

$ET_o = 0.0135\ (T + 17.78) * Rs$ (30)

Where;

ET_0 = reference crop evapotranspiration, well watered grass in mm day^{-1},

T = average daily temperature (^oC),

Rs = incident solar radiation (mm day^{-1})

3-3-5. FAO Blaney-Criddle formula (Doorenbos and Pruitt, 1977)

The general form of FAO Blaney-Criddle formula is

$ETo = \{a + b\ [P(0.46\ T + 8.13)]\}$ (31)

Where;

ET_0 = reference crop evapotranspiration, well watered grass in mm day^{-1},

T = average daily temperature (^oC),

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

a and b = correction factors where;

$a = 0.0043\ (RHmin) - (n/N) - 1.41,$ (32)

$b = 0.82 - 0.0041(RHmin) + 1.07(n/N) - 0.066\ (U_d) - 0.006(RHmin)\ (n/N) - 0.0006(RHmin)\ (U_d)$ (33)

n/N ratio = $2*Rs/Ra - 0.5$

U_d = wind speed at 2 m height (m s^{-1}), about zero inside plastic houses.

n/N = the ratio of actual to possible sunshine hours, RHmin = mean minimum daily relative humidity (%)

3-3-6. Jensen – Haise

Jensen and Haise (1963) and Hansen *et al.* (1977) estimated evapotranspiration for alfalfa reference crop using the following equation:

$ET_r = C_T (T_a - T_x) Rs$ (34)

where;

ET_r = potential evapotranspiration for alfalfa reference crop (mm day^{-1}),

$C_T = 1/(C_1 + C_2 C_H)$ (35)

$C_H = 50/(e_2 - e_1)$ (36)

$C_1 = 38 - (2\ Elev/305)$ (37)

$C_2 = 7.3\ ^{o}C$ (38)

T_a = mean temperature (^{o}C)

$T_x = -2.5 - 0.14\ (e_2 - e_1) - Elev/550$ (39)

Elev= elevation (m),

e_2 and e_1 = the saturation vapour pressure (mb) at the mean maximum and mean minimum temperature for the warmest month of the year.

3-4. Crop coefficient (K_c)

The crop coefficient (K_c) of tomato and cucumber were calculated by dividing the crop evapotranspiration (Et_c) by the crop reference evapotranspiration (ET), so two types of Kc for each crop (tomato and cucumber) were calculated using grass (Et_o) and alfalfa (ET_r) as reference crops in this study.

$$Kc_{Alfalfa} = \frac{Et_c}{ET_r} \qquad (40)$$

$$Kc_{grass} = \frac{Et_c}{ET_o} \qquad (41)$$

where

$Kc_{Alfalfa}$ = crop coefficient using alfalfa as a reference crop,

Kc_{grass} = crop coefficient using grass as a reference crop.

4. RESULTS AND DISCUSSIONS

4-1. Soil properties.

Selected soil physical and chemical properties are presented in Table1. Soil texture is clay.

4-2. Soil Characteristic curves.

Soil water characteristic curves for 0-15, 15-30, 30-45, 45-60, 60-75, and 75-90 cm depths are shown in Figures (5), (6), (7), (8), (9) and (10), respectively. For each depth logarithmic relationships are obtained between soil moisture and soil moisture tension.

4-3. Climatic data.

4-3-1 Open field

Minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), wind velocity (U, Km day^{-1}), atmospheric pressure (kPa), actual sunshine hours (n), and incident solar radiation (Rs, W $m^{-2}day^{-1}$) taken from the meteorological station of Deir-Alla are presented in appendix 1, Table1.

Table 1. Selected physical and chemical properties of soil at Deir-Alla Research Station in the Jordan Valley 1999/2000.

Soil Depth cm	SG (1)	FC % (2)	PWP % (3)	Mechanical Analysis Sand %	Silt %	Clay %	Textural class (4)
0 - 15	1.33	31.00	19.95	13.9	31.9	54.2	Clay
15-30	1.35	32.50	21.59	10.3	33.7	56.0	Clay
30-45	1.32	33.00	21.95	13.7	28.4	58.9	Clay
45-60	1.45	34.50	22.90	8.2	32.0	59.8	Clay
60-75	1.46	34.80	22.95	11.6	32.1	56.3	Clay
75-90	1.50	35.69	23.00	14.9	32.2	52.9	Clay

Soil depth cm	N %	P ppm	K ppm	pH	EC_e dS m^{-1}
0-15	0.112	67	812	7.8	3.2
15-30	0.089	62	696	7.7	2.2
30-45	0.056	70	627	7.7	2.4

(1) Specific gravity.

(2) Field capacity, % by volume.

(3) Wilting point, % by volume.

(4) Classification of soil particles according to U.S. system: sand 0.05-2.00 mm, silt 0.002-0.05 mm, and clay < 0.002 mm.

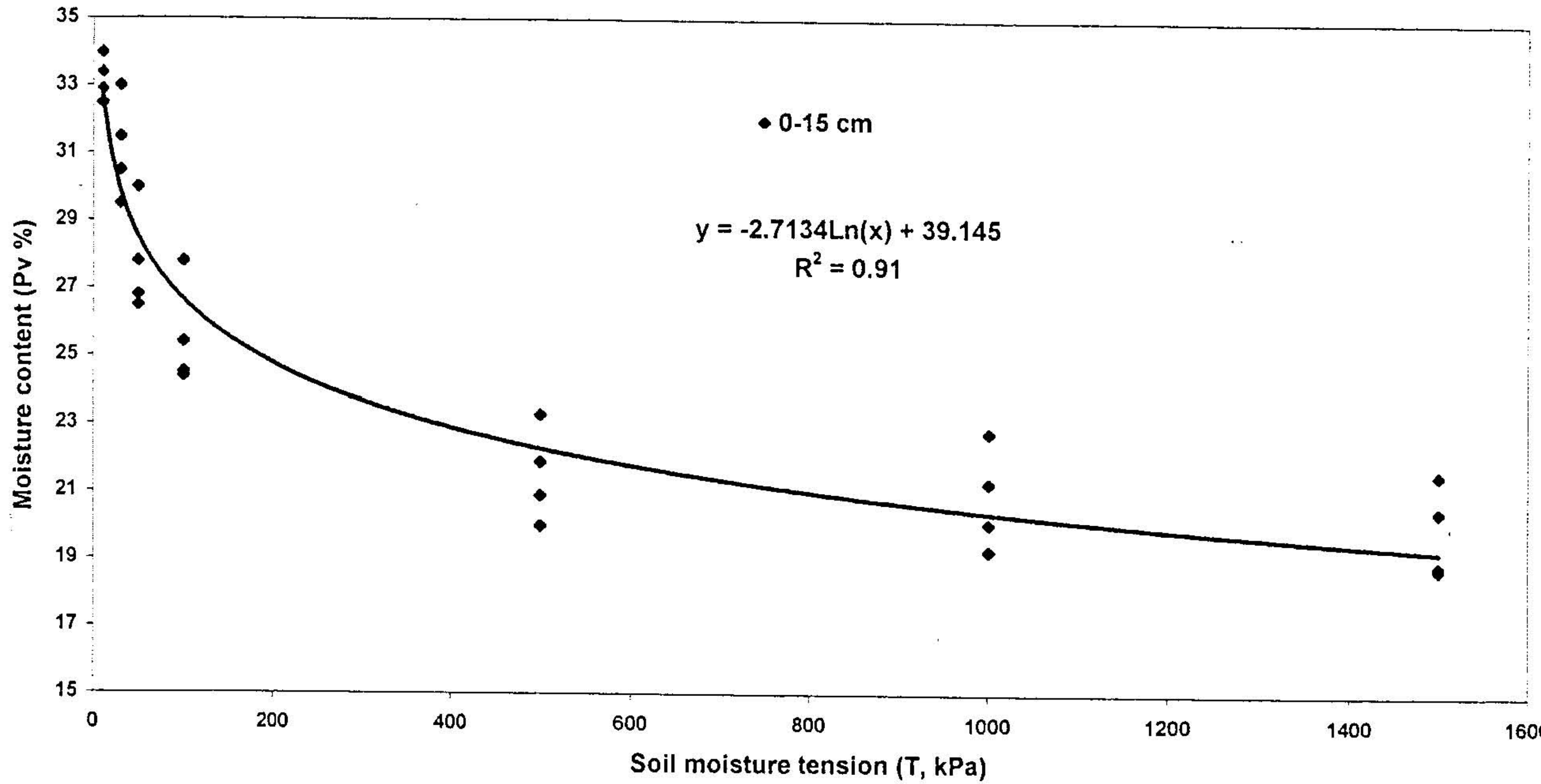


Figure 5. Soil-water characteristic curves, for 0-15 cm soil depth, at the experimental site of Deir-Alla Research Station.

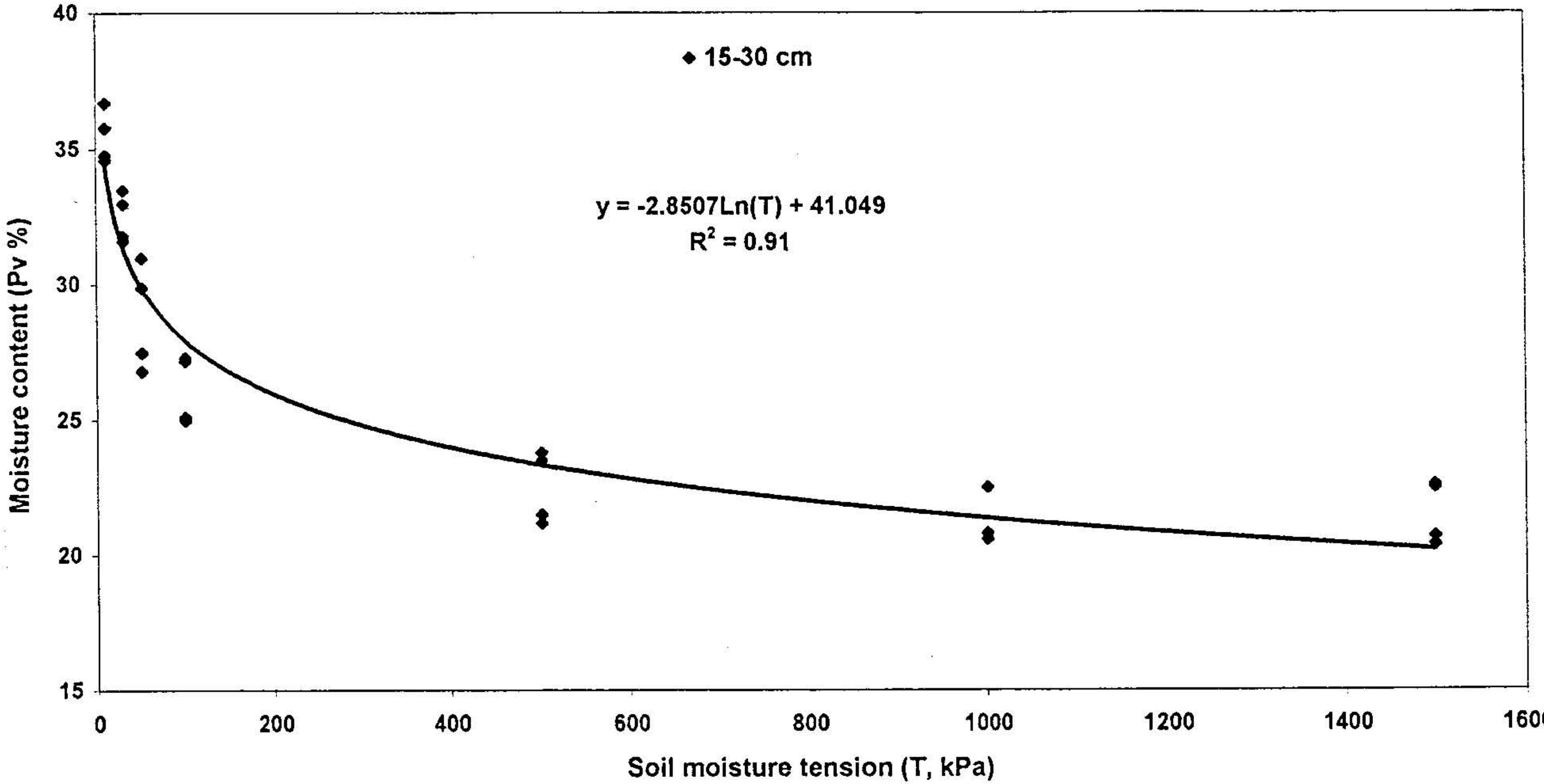


Figure 6. Soil-water characteristic curves for 15-30 cm soil depth, at the experimental site of Deir-Alla Research Station.

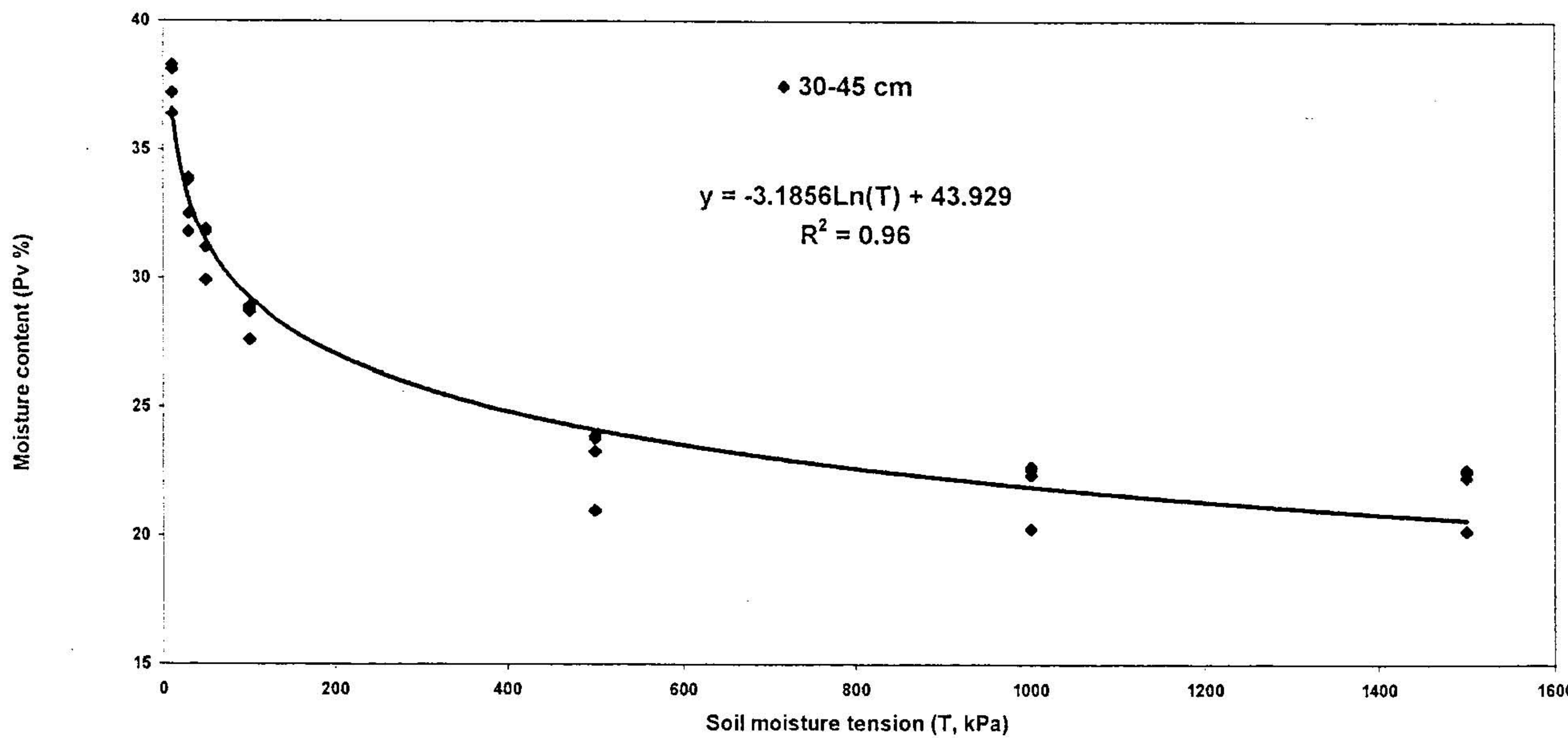


Figure 7. Soil-water characteristic curves for 30-45 cm soil depth, at the experimental site of Deir-Alla Research Station.

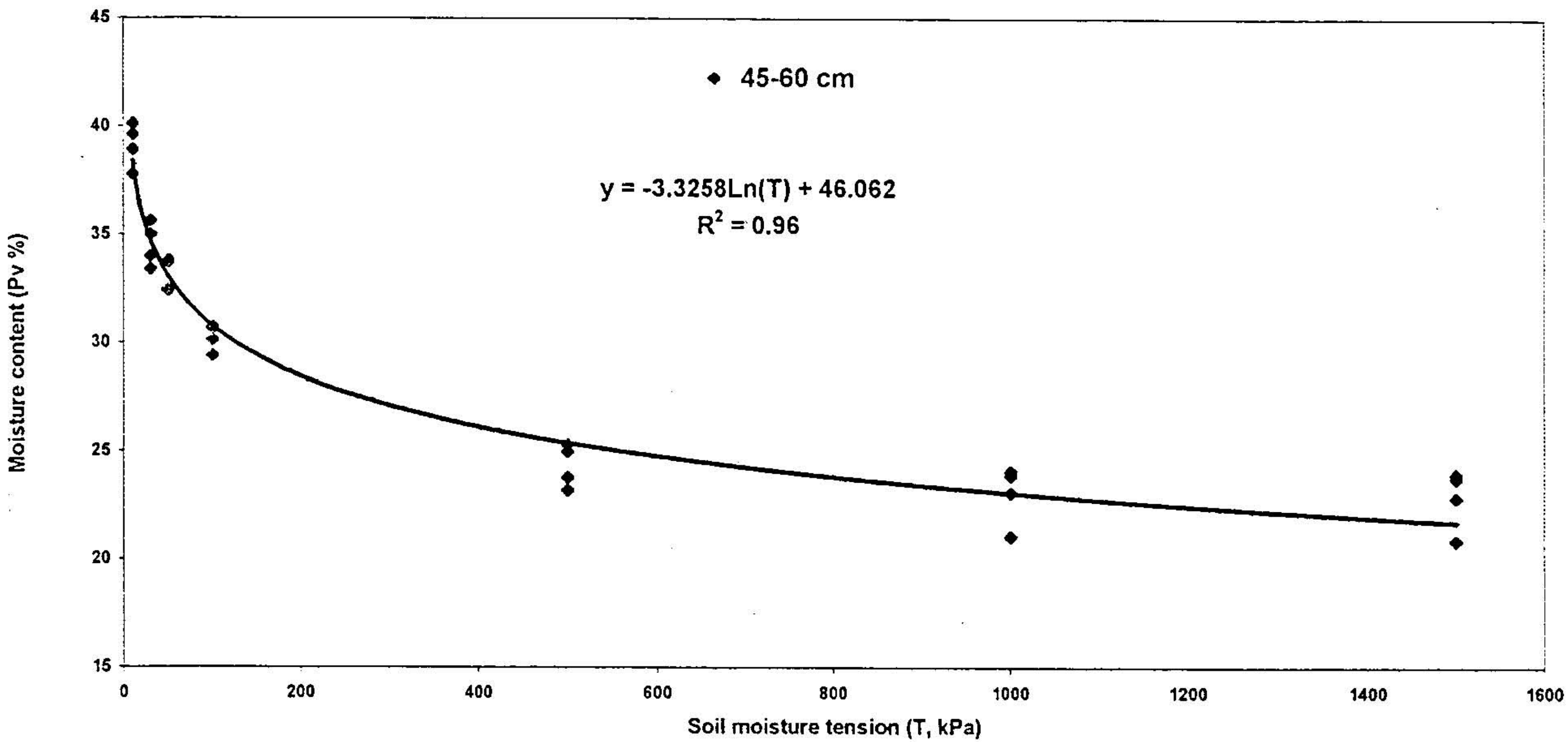


Figure 8. Soil-water characteristic curves for 45-60 cm soil depth, at the experimental site of Deir-Alla Research Station.

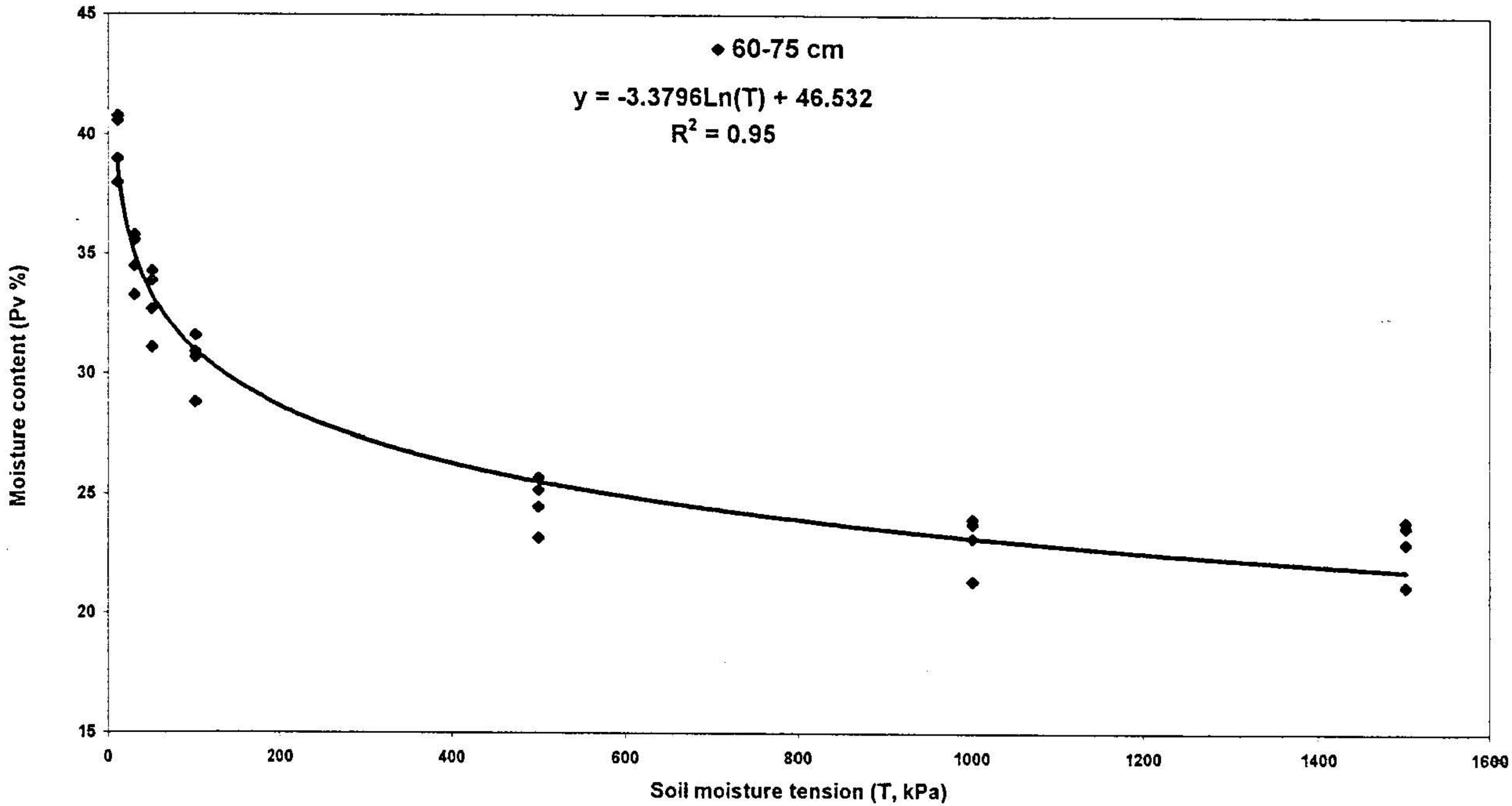


Figure 9. Soil-water characteristic curves for 60-75 cm soil depth, at the experimental site of Deir-Alla Research Station.

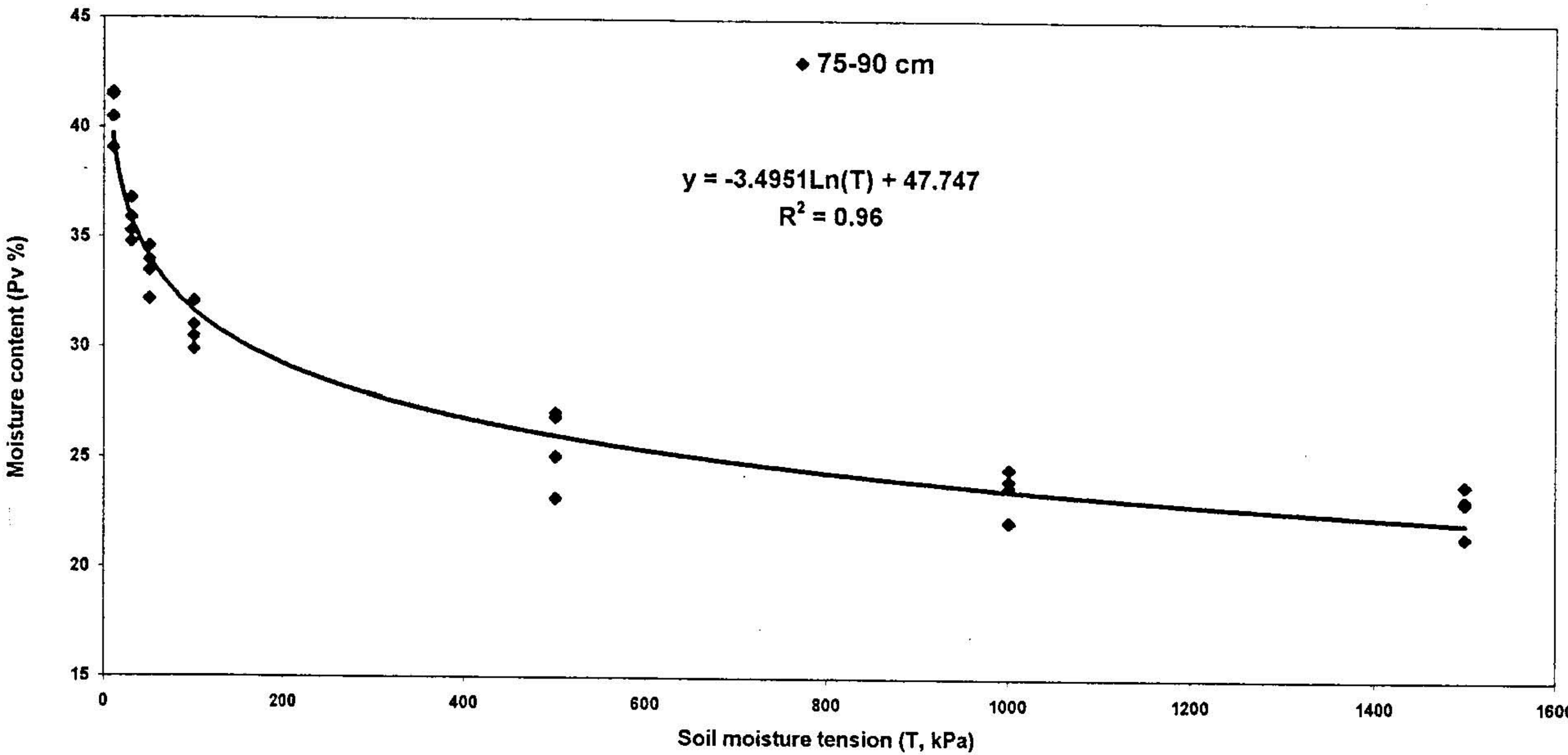


Figure 10. Soil-water characteristic curves for 75-90 cm soil depth, at the experimental site of Deir-Alla Research Station.

4-3-2 Inside plastic houses

In each plastic house daily Tmin (°C), Tmax (°C), RHmin(%), RHmax (%) and Rs were collected and presented on a weekly basis in Appendix 1 Tables 2, 3, 4, and 5 for grass, alfalfa, tomato and cucumber crops, respectively.

Incident solar radiation (Rs) inside each plastic house was estimated from outside Rs values using SunScan readings in both sites at the same time. From these readings the inside to outside Rs ratio for the four plastic houses were determined. The Rs inside to Rs outside ratio were 0.43, 0.45, 0.55 and 0.59 for the plastic houses planted with cucumber, tomato, alfalfa and grass, respectively.

4-4. Yield and Plant Parameters.

Table 2 shows average plant yield, total water applied, actual evapotranspiration (Eta), and water use efficiency (WUE) for grass, alfalfa, tomato and cucumber under plastic house conditions. Water use efficiency is the marketable crop yield per unit of water used in evapotranspiration (Power, 1983).

Total tomatoes yield was 141.27 ton ha^{-1} under 429 mm of applied irrigation water. Eta was 356 mm and WUE was 396.6 Kg mm^{-1} ha^{-1}. Suwwan *et al.* (1985) showed that tomato plants recevied 490 mm of applied water inside a plastic house using black mulch, resulted in a yield of 84 ton ha^{-1}, and water use efficiency 172 kg mm^{-1} ha^{-1}. In the Jordan

Table 2. Average plant yield, total water applied, irrigation application efficiency (E_a), actual evapotranspiration (Eta) using depletion method, and water use efficiency (WUE) for grass, alfalfa, tomato, and cucumber, under plastic house conditions.

Crop	Yield (ton ha^{-1})	Water applied (mm)	E_a %	Eta (mm)	WUE (kg mm^{-1} ha^{-1})
Grass FW	85.7	427.5	80	326.7	262.4
DW	21.9				67.0
Alfalfa FW	100.6	500.3	81	403.4	249.3
DW	13.80				34.2
Tomato	141.3	428.6	85	356.2	396.6
Cucumber	133.5	275.0	87	213.8	624.4

FW = Fresh weight

DW = Dry weight at 70 °C

Valley, Oweis *et al.* (1988) also showed that maximum yield of tomato was 158 ton ha^{-1} produced with 600 mm of net irrigation, under plastic house conditions. In open field, Doorenbos and Kassam (1979) reported that good commercial yield of tomato (*Lycopersion esculentum*) under irrigation is 45-65 ton ha^{-1} with WUE of 100-120 kg mm^{-1} ha^{-1}. Thus inside plastic houses, in this study, tomato yield and WUE was almost 3 to 4 times higher than that in open field (Doorenbos and Kassam, 1979).

The WUE of cucumber was about 1.6 times higher than that of tomato. The high value of WUE of cucumber was due to low Eta values which related to low LAI and high air relative humidity inside the plastic house, during the growing season (152 days).

The obtained dry yield (hay with 12 percent moisture) of alfalfa are similar to the results reported by Doorenbos and Kassam (1979), where in open field good yield is in the range of 2-2.5 ton ha^{-1} per cut (hay with 10-15 percent moisture). However, these findings disagree with Doorenbos and Kassam's results of WUE values (15 to 20 kg mm^{-1} ha^{-1}). The reason for this wide difference in WUE values of open field and inside plastic house conditions, is the low value of Eta inside plastic houses.

The irrigation application efficiency (E_a) is defined as the ratio of the average depth of the irrigation water stored in the root zone to the average depth of irrigation water applied (Jensen, 1967). The drainage water was estimated for each irrigation event as suggested by Abu-Awwad (2001)

$d_{Etc} = d_2 - d_1$

$d_2 = d_1 + d_w$; where d_2 d_{FC}

$d_D = 0.0$

If $d_2 > d_{FC}$, then $d_2 = d_{FC}$ and

$d_D = d_W - d_{Etc}$

where: d_{Etc} is the measured soil water depletion depth; d_1 and d_2 are the equivalent depths of moisture in the root zone just before and after irrigation, respectively; d_D is the drainage water depth; and d_W is the water depth applied. The E_a for cucumber and tomato plastic houses are higher than that of grass and alfalfa plastic houses by 5-7 % (Table 2). This variation was due to small distance between laterals in grass and alfalfa (40 cm) compared with that for cucumber and tomato (135 cm) plastic houses. So the drainage water was more in grass and alfalfa because of the overlapping drippers discharge. All calculated E_a values at the end of the growing season were less than assumed E_a (90%). This might have been due to drippers manufacturing and soil variations.

Weekly plant height and leaf area index (LAI) for the four crops inside plastic houses are shown in Appendix 1, Tables 6 and 7, respectively. The fluctuations in plant height and LAI values for grass and alfalfa are due to the plant cutting. Interpolation equations between plants height and LAI and net solar radiation (Rn) were developed for the four crops (Appendix 1, Tables 8 and 9), by which the daily LAI can be estimated from plant height only, and Rn can be estimated from plant height and solar radiation (Rs). These regressions were used for calculating the average weekly values of LAI and Rn during the growing season from daily plant height.

4-5. Actual evapotranspiration of tomatoes, cucumbers, alfalfa and grass by depletion method (Eta).

Actual annual evapotranspiration (Eta) values of tomato, cucumber, alfalfa and grass crops were determined by the depletion method using TRIME technique. They were: 356.3; 213.8; 403.4; and 326.7 mm, respectively (Table 3). Tomatoes have higher Eta value than cucumbers due to physiological reasons (plant leaf area index and height),and due to long growing season and high temperature specially in the last two months of the growing period of tomato (Appendix 1, Table 4).

Average daily Eta values for tomato, cucumber, alfalfa and grass crops on monthly basis are shown in Table 3. Weekly Eta values during the growing season are shown in Figure (11). In general Eta values for tomato and cucumber crops were low at the beginning of the growing season because of the small LAI since the plants were at initial stage, then increased until they reached maximum values in April and May, with fluctuation sometimes occurred due to cultural practices. such as plant thinning (Fig. 11) and climatic conditions like low temperature and

Table 3. Average daily evapotranspiration (mm day^{-1}) measured by depletion method using TRIME technique for tomato (Eta_T), cucumber (Eta_C), alfalfa (ET_r) and grass(ET_o) on monthly basis inside plastic houses.

Month	Eta_T	Eta_C	ET_r	ET_o
Nov	0.49	1.03	1.68	1.36
Dec	0.65	0.91	1.61	1.05
Jan	0.95	1.23	1.5	1.07
Feb	1.33	1.59	1.88	1.4
Mar	1.96	1.67	2.19	1.92
April	3.23	2.2	2.63	1.99
May	3.34		2.65	2.65
Total (mm)	**356.23**	**213.84**	**403.39**	**326.73**

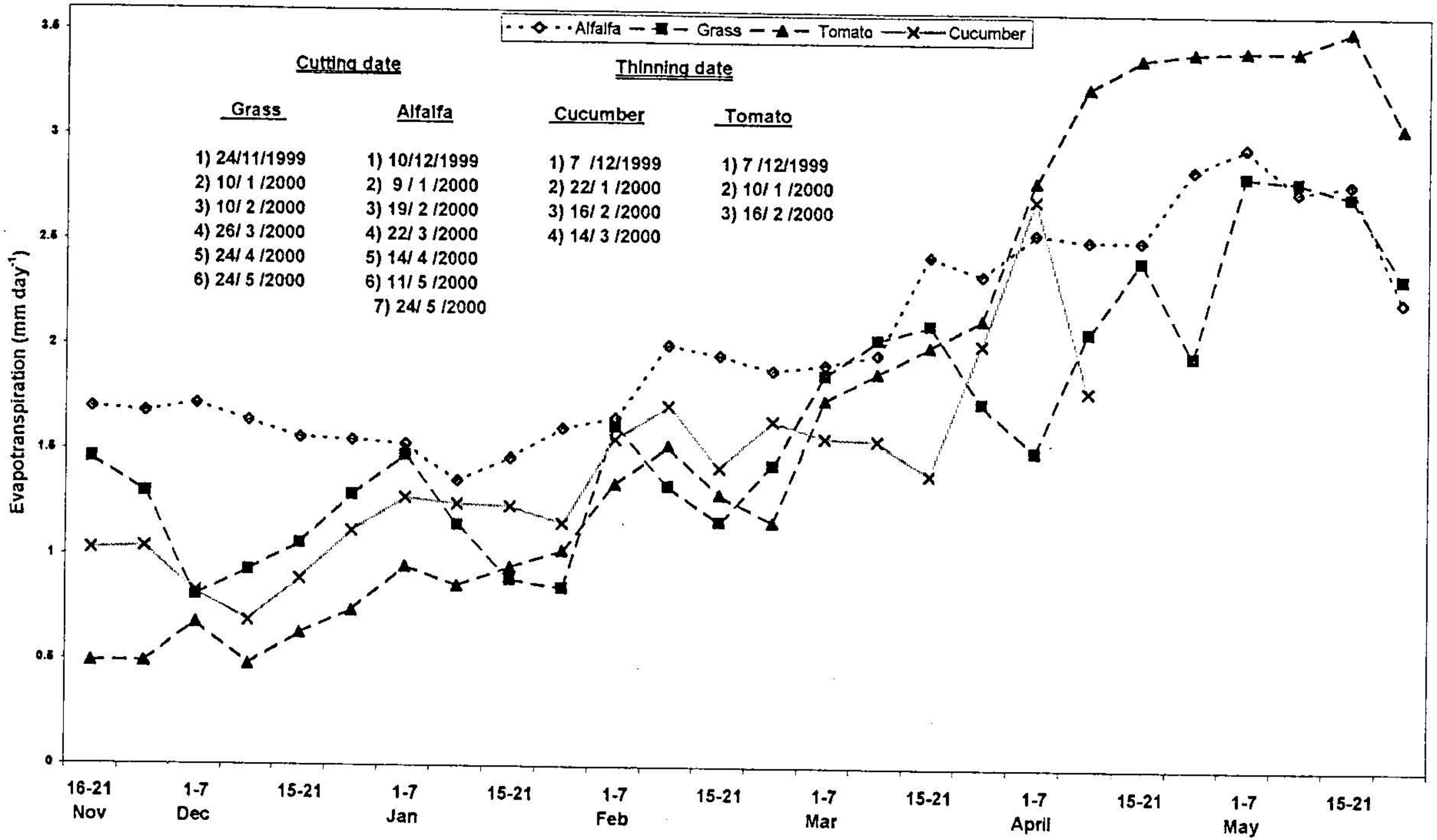


Figure 11. Actual evapotranspiration (Eta) on weekly basis for alfalfa, grass tomato and cucumber crops under plastic house condtions.

high RH inside plastic houses (cucumber crop for example, the Eta during 8-14 February was 1.72 mm day^{-1} then it decreased to 1.43 mm day^{-1} on 15-21 February, the reason for this reduction was due to increased in RHmax from 90 to 100% and the reduction in the Rs value from 61.1 to 56.9 W M^{-2} day^{-1}, (Appendix 1, Table 5)). Cucumber Eta values were higher than tomato Eta values in the first three months after planting date due to fast cucumber growth rate, after that tomato Eta values were sharply increased during April and May, where tomato plants reached its maximum leaf area index (LAI) and maturity stage in addition to high temperature values which occurred during these months (Appendix 1, Table 4). The reduction in Eta values during the last weeks of the growing season (Fig. 11) for cucumber and tomato are due to cutting of irrigation at the end of the growing season when no more marketable plant yield produced.

The fluctuations in the Eta values for alfalfa and grass are due to the climatic changes and cutting during the growing season. All the ET_r values for alfalfa were more than that for grass crop (ET_o) during the whole growing season. This agrees with the finding of Wright (1996) in open fields. The average daily calculated ET_0 is linearly related to ET_r by: $ET_o = 0.8248\ ET_r$, $R^2 = 0.67$ (Fig. 12). For the entire data set, the average grass reference ET_0 was 81% of alfalfa reference ET_r.

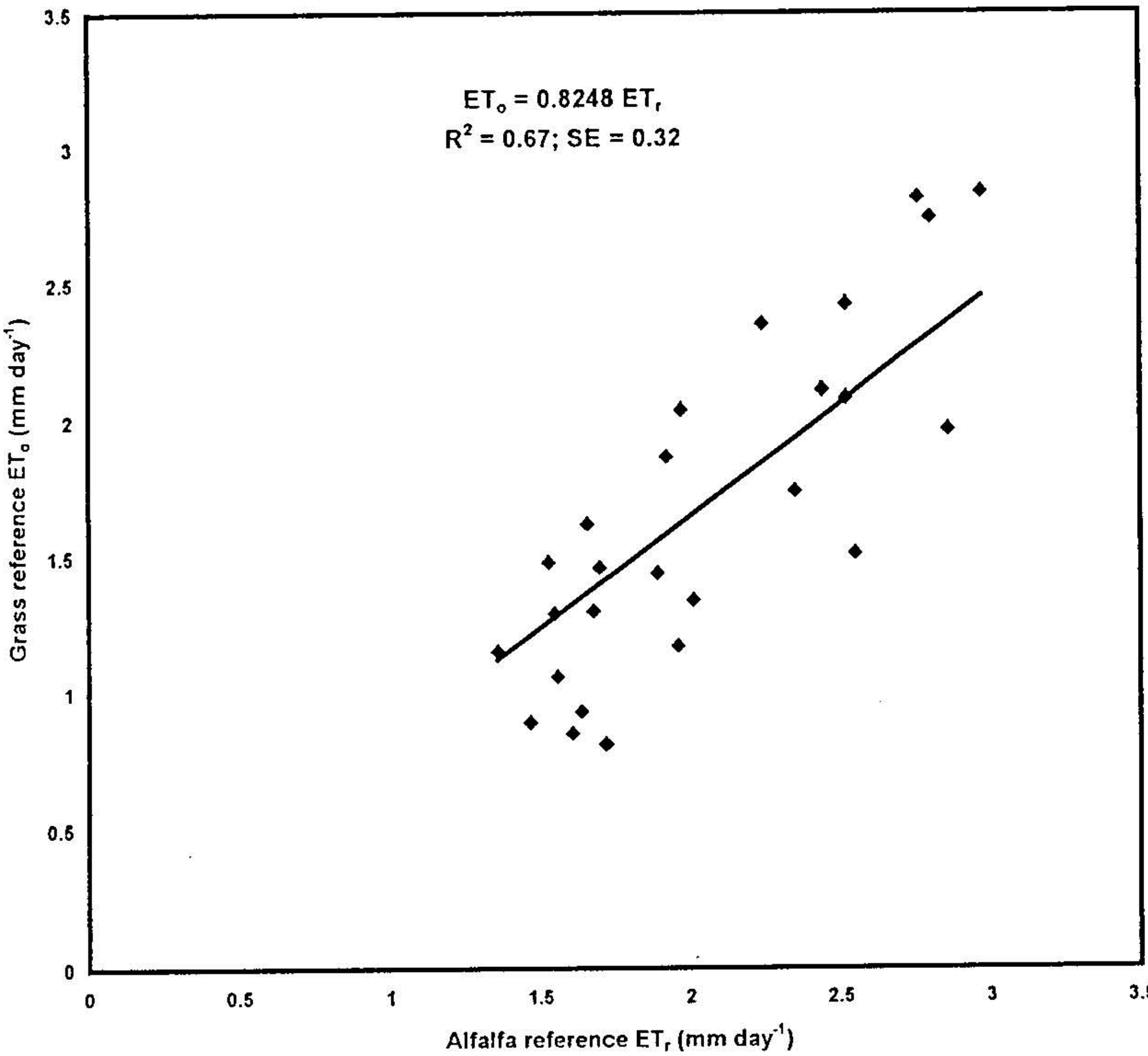


Figure 12. Average daily culculated grass reference ET_o versus calculated alfalfa reference ET_r on weekly basis under plastic house conditions.

4-6. Crop coefficients (Kc) of tomato and cucumber under plastic house conditions.

Table 4 shows the average Kc values for tomatoes and cucumbers using grass and alfalfa as reference crops on monthly basis. The Kc values for tomato and cucumber were calculated according to the phenological growth development stages from the measured Kc values using the method prposed by Allen *et al.* (1998). The calculated Kc values and the reported FAO- Kc values in open fields for tomato and cucumber were presented in Tables 5 and 6, respectively. The calculated Kc value for tomato during the growing season ranges from 0.53 to 1.29 as compared to 0.6 to 1.15 reported by Allen *et al.* (1998) in open field using grass reference crop (Fig. 13). The low Kc values for tomato at initial and development stages inside the plastic houses were due to lower LAI and plant thinning. The Kc values for tomato inside the plastic house were about 1.2 to 2 times of the reported values in the open field during the mid-season and late stages (Figures 13 and 14). During these periods tomato plants reached the highest LAI (>4) and yield (about five times higher than that in open field) in addition to high temperature which increased ET values for tomato inside the plastic house. Table 6 shows the variation of the calculated Kc values for cucumber during the growing period, the highest Kc value attained during mid season where crop water demand was the highest. The

Table 4. Average daily crop coefficients for tomatoes (Kc_{To} and Kc_{Tr}) and cucumbers (Kc_{Co} and Kc_{Cr}) using grass and alfalfa as reference crops, respectively, on monthly basis inside plastic houses.

Month	Kc_{To}	Kc_{Tr}	Kc_{Co}	Kc_{Cr}
Nov	0.36	0.29	0.76	0.61
Dec	0.62	0.40	0.87	0.57
Jan	0.89	0.63	1.15	0.82
Feb	0.95	0.71	1.14	0.85
Mar	1.02	0.89	0.87	0.76
April	1.62	1.23	1.11	0.84
May	1.26	1.26		

Table 5. Crop coefficients values for tomato crop inside the plastic houses.

	Initial	Crop Devt	Mid-season	Late season
Growth Period	1-38	39-87	88-170	171-198
Kc1	0.53	0.89	1.25	1.29
Kc2	0.34	0.65	0.96	1.26
Kc*	0.60	0.88	1.15	0.80

Kc1 = Kc values of tomato inside the plastic houses using grass as reference crop.

Kc2 = Kc values of tomato inside the plastic houses using alfalfa as reference crop.

Kc* = Reported Kc values for tomato in open field using grass. (Allen et al. 1998)

Table 6. Crop coefficients values for cucumber crop inside the plastic houses.

	Initial	Crop Devpt	Mid-season	Late season
Growth Period	1-29	30-70	71-128	129-152
Kc1	0.74	0.89	1.03	0.87
Kc2	0.49	0.64	0.79	0.71
Kc*	0.60	0.80	1	0.75

Kc1 = Kc values for cucumber inside the plastic houses using grass reference crop.

Kc2 =Kc values for cucumber inside the plastic houses using alfalfa reference.

Kc* = Kc values for cucumber in open field using grass. (Allen et al. 1998)

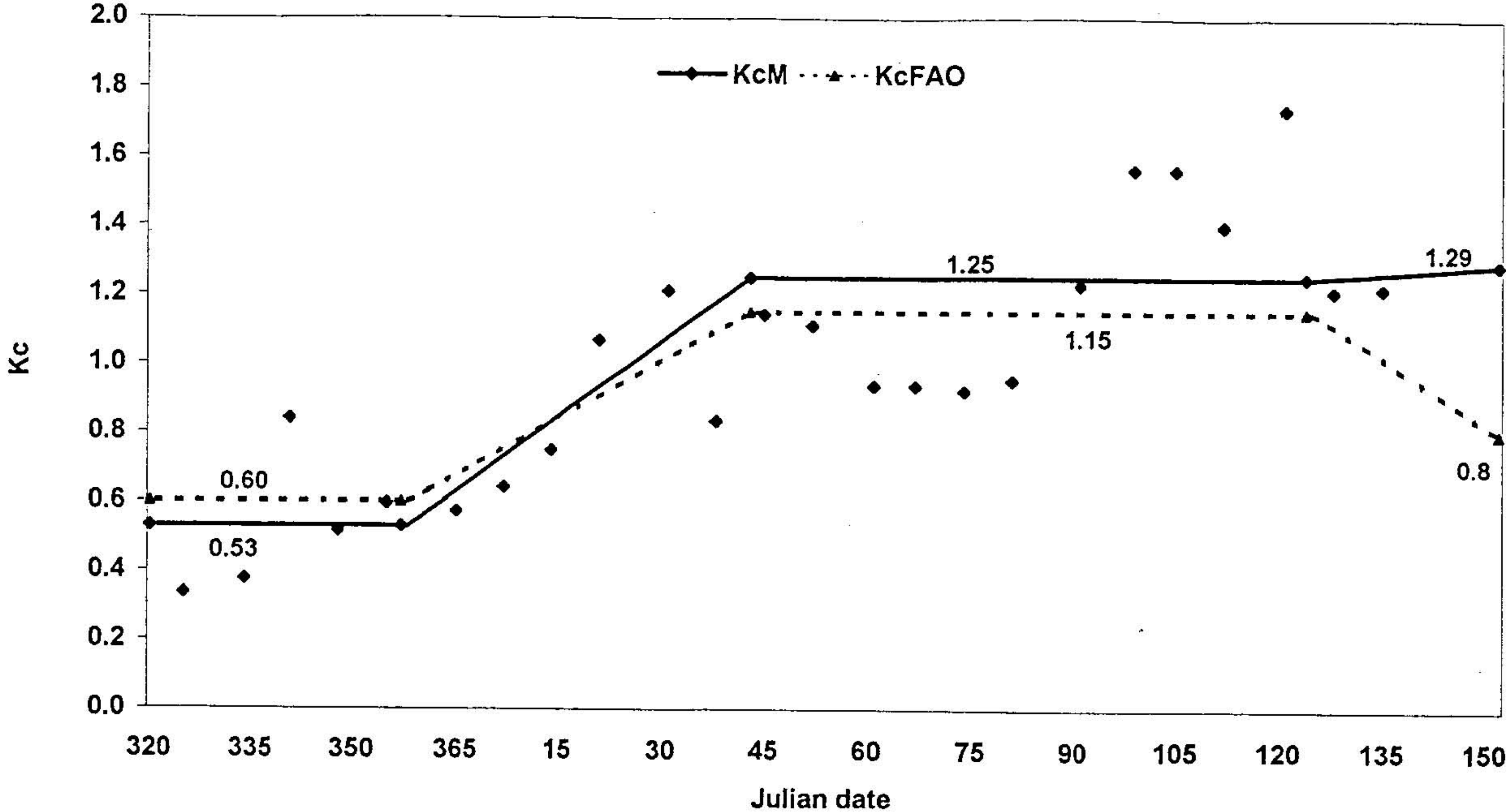


Figure 13. Measured crop coefficient curve inside the plastic houses (Kc_M) and FAO curve in open field (Kc_{FAO}) for tomato using grass reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

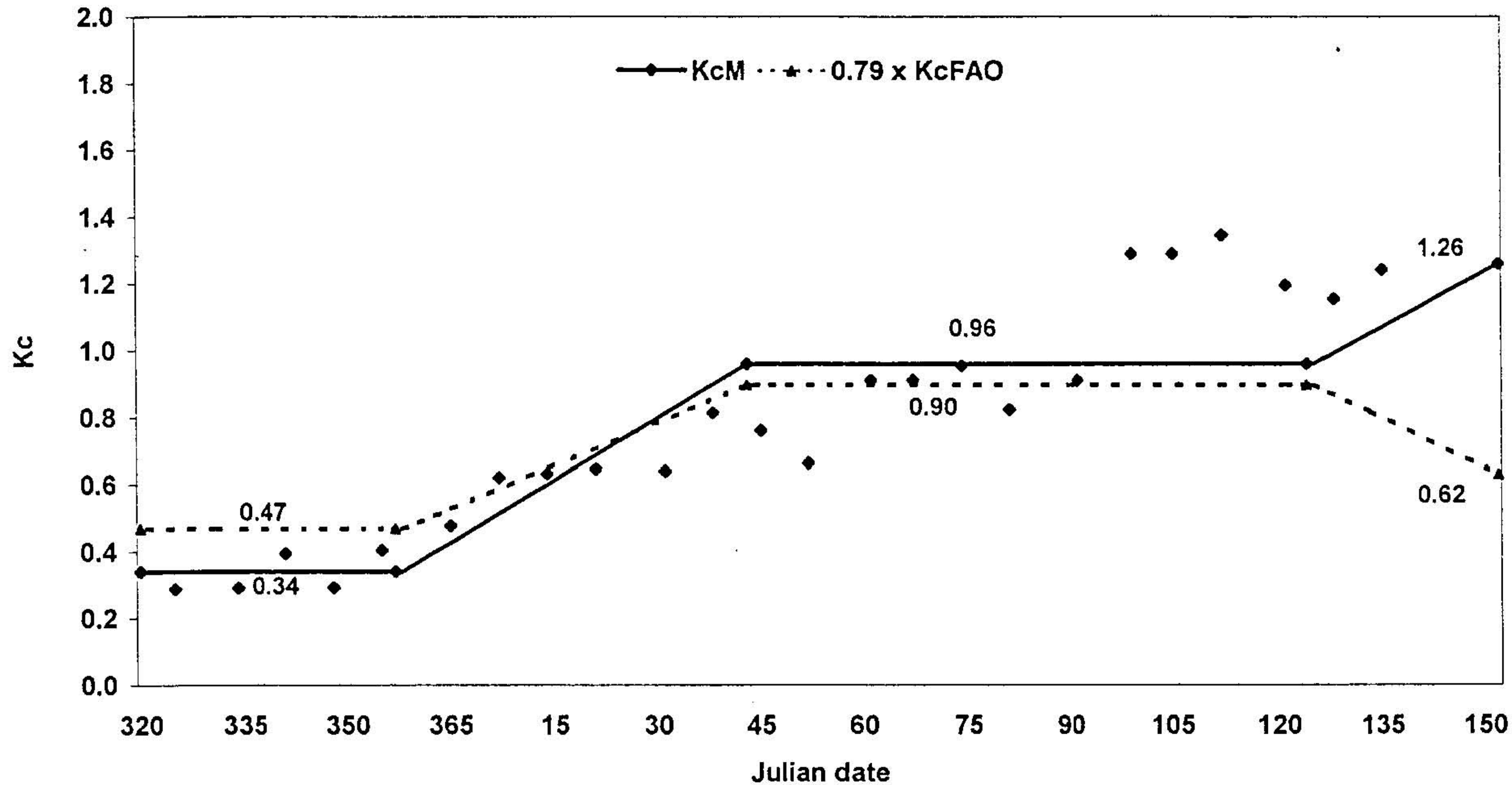


Figure 14. Measured crop coefficient curve inside the plastic houses (Kc_M) and FAO curve in open field (0.79 x Kc_{FAO}) for tomato using alfalfa reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

higher Kc values for cucumber inside the plastic houses compared with the reported Kc values in open field using grass reference crop is due to higher LAI and yield inside the plastic houses (Fig. 15). The measured Kc (Kc_M) values for cucumber were very closed to the reported0.79x Kc_{FAO} in open field using alfalfa reference crop during initial and mid-season growth stages. While at the end growth stage Kc_M value was higher than that of reported 79x Kc_{FAO} because of the frequent irrigation and the high LAI inside the plastic house when compared with open field (Fig. 16). The Kc values based on grass as a reference crop were almost higher than Kc values based on alfalfa reference crop for tomatoes and cucumbers during the growing season. The fluctuations of Kc values for tomato and cucumber were due to cutting of reference crops (grass and alfalfa), and thinning of tomato and cucumber, in addition to variations in climatic factors during the growing season. So, the obtained Kc values can not be used for irrigation scheduling but can be used only in planning according to phenological plant growth stages. The fluctuations of Kc values for tomato and cucumber using grass as reference crop were higher than that when using alfalfa as reference crop. This phenomena was due to two reasons: First, the growth rate of alfalfa was higher and as a result alfalfa recovered the ground sooner than grass; and Second alfalfa crop was cut manually by hand at 12 cm height, while the grass crop was cut by machine at lower height 5cm. The study was terminated on April 16,

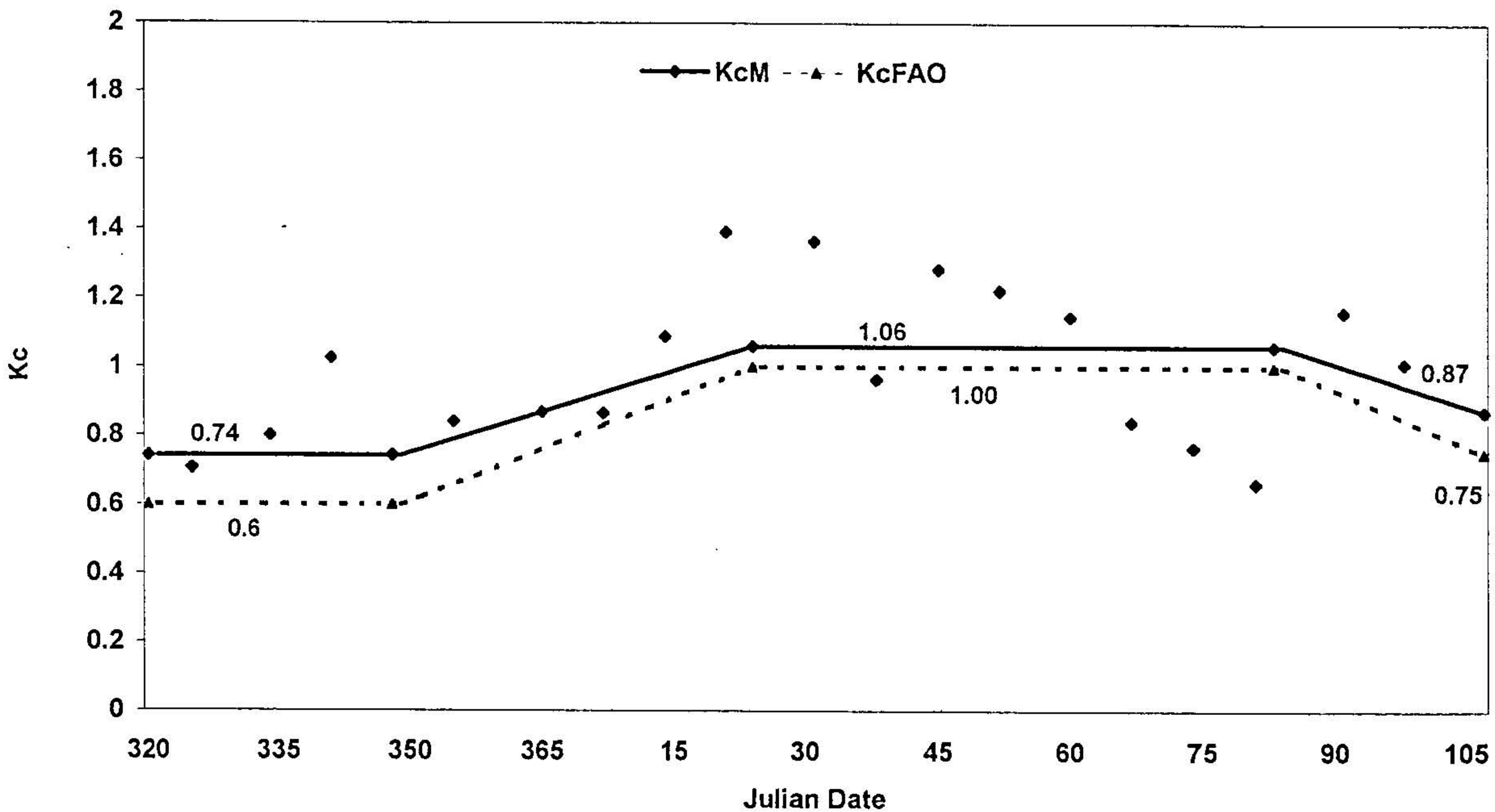


Figure 15. Measured crop coefficient curve inside the plastic houses (Kc_M) and FAO curve in open field (Kc_{FAO}) for cucumber using grass reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

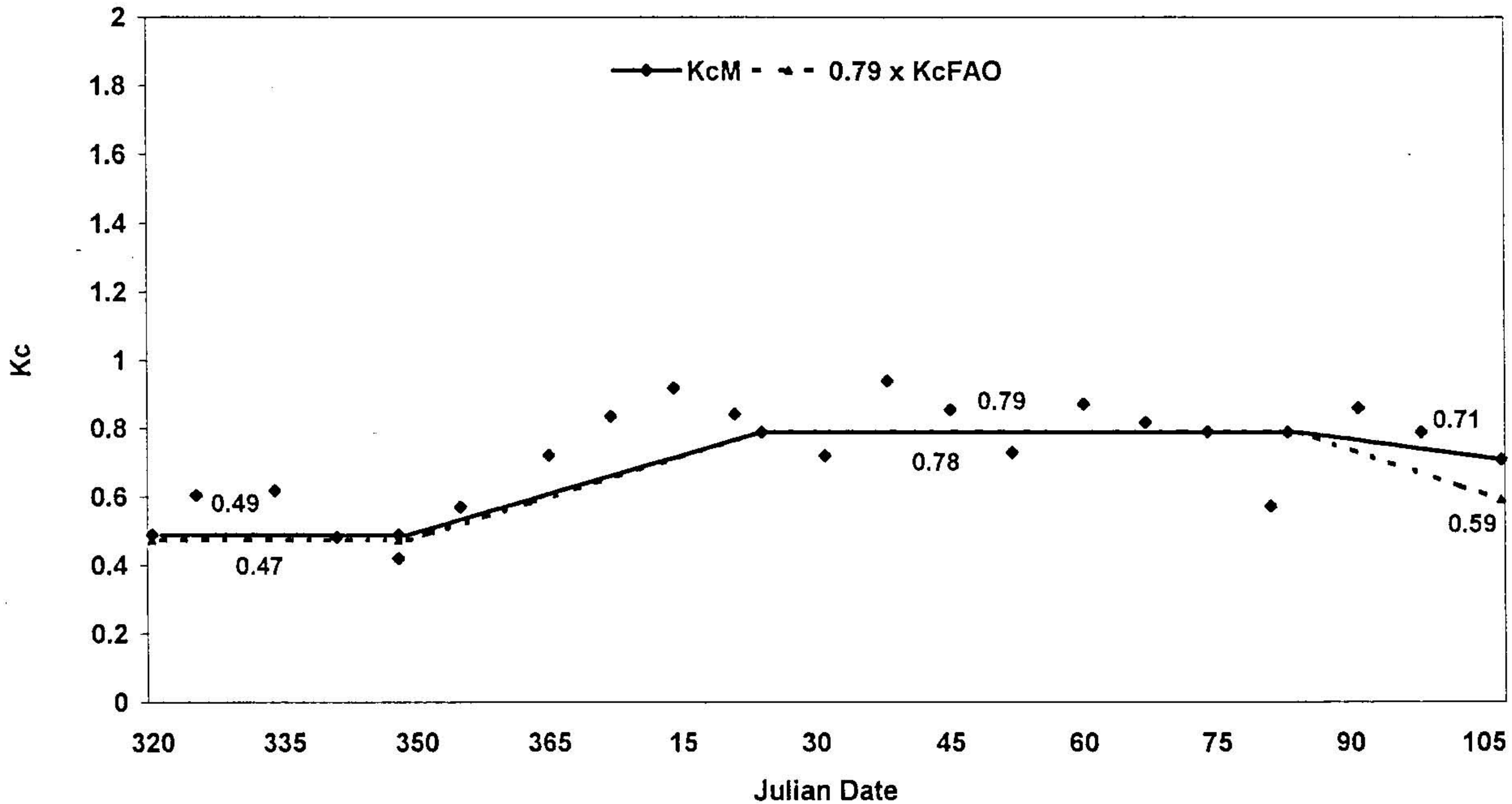


Figure 16. Measured crop coefficient curve inside the plastic houses (Kc_M) and FAO curve in open field (0.79 x Kc_{FAO}) for cucumber using alfalfa reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

2000 for cucumber crop and on May 31, 2000 for tomato plant when no more marketable yield was produced.

4-7. Prediction of potential evapotranspiration in open fields using Penman-Monteith equation.

Potential evapotranspiration of grass (ET_o) and alfalfa (ET_r) were estimated in open fields, nearby the plastic houses, using Penman-Monteith equation. The estimated ET_o and ET_r values on weekly and monthly basis are presented in Tables 7 and 8, respectively.

Figure (17) shows average daily calculated grass reference ET_o versus calculated alfalfa reference ET_r using Penman-Monteith equation in open fields, on weekly basis. The mean daily ET_o is linearly related to ET_r by: 0.7863 ET_r, $R^2 = 0.98$. For the entire data set, total ET_o = 863 mm compared to ET_r = 1093 mm so that on the average, grass reference ET_o was 79% of alfalfa reference ET_r. Allen *et. al.* (1994) found a similar result in arid location in Califoronia (ET_o = 0.75 ET_r). But, in humid locations like in Zaire, the ET_o = 0.89 ET_r. While Wright (1996) found ET_o was 83% of ET_r on a seasonal basis for open field in Idaho. Figure (18) shows average mean daily estimated grass reference ETa by depletion method inside a plastic house versus calculated grass reference ET_o using Penman-Monteith equation in open fields on weekly basis. The daily Eta is linearly

Table 7. Average daily evapotranspiration (mm day^{-1}) calculated by Penman-Monteith equation for grass(ET_o) and alfalfa (ET_r) on weekly basis in open fields.

Month	Period	ET_o	ET_r
Nov	16-21	4.53	6.62
	22-30	3.38	4.64
Dec	1-7	2.93	4.04
	8-14	3.05	4.11
	15-21	3.44	5.02
	22-31	2.58	3.26
Jan	1-7	2.56	2.99
	8-14	2.46	3.26
	15-21	3.31	4.48
	22-31	2.54	3.00
Feb	1-7	3.17	4.19
	8-14	3.82	5.24
	15-21	3.28	3.78
	22-29	3.33	3.97
Mar	1-7	3.45	3.85
	8-14	3.72	4.53
	15-21	4.68	5.95
	22-31	4.61	5.50
April	1-7	5.96	7.42
	8-14	5.83	7.13
	15-21	6.90	8.66
	22-30	6.27	7.82
May	1-7	7.00	8.94
	8-14	7.21	9.24
	15-21	7.27	9.12
	22-31	7.25	8.93
Total (mm)		863	1093

Table 8. Average daily evapotranspiration (mm day^{-1}) calculated by Penman-Monteith equation for grass(ET_o) and alfalfa (ET_r) on monthly basis in open fields.

Month	ET_o	ET_r
Nov	3.71	5.25
Dec	2.95	4.03
Jan	2.69	3.38
Feb	3.36	4.22
Mar	4.15	4.97
April	6.24	7.76
May	7.19	9.04
Total (mm)	863	1093

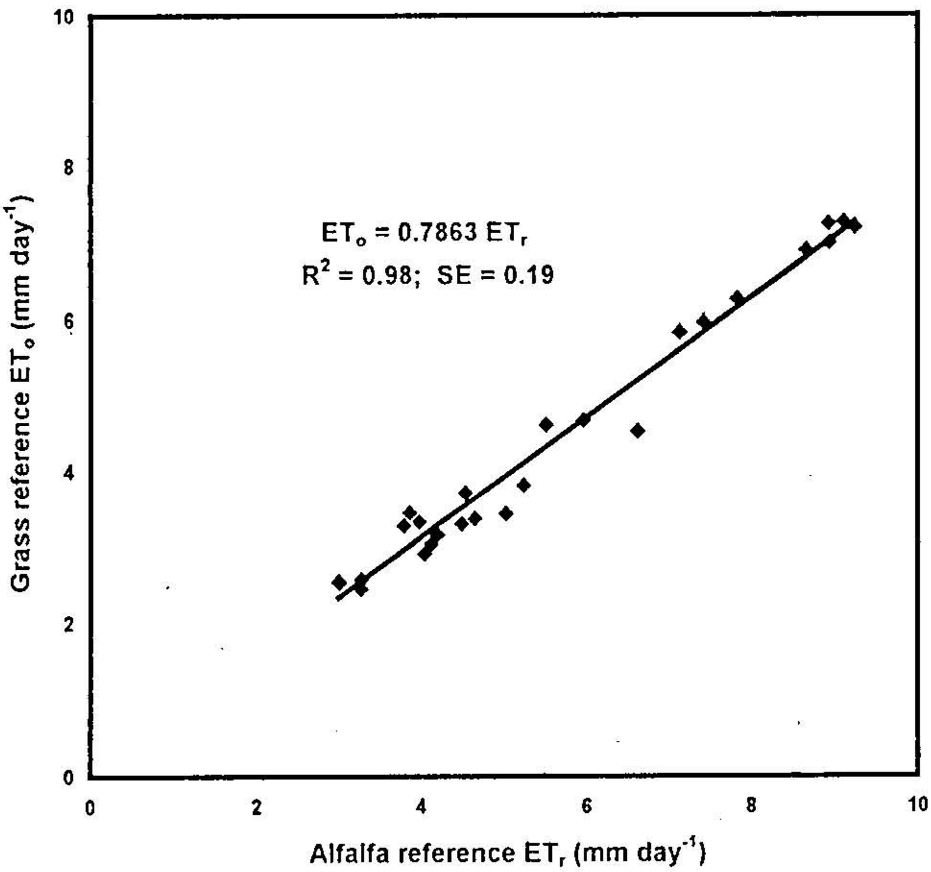


Figure 17. Average daily estimated grass reference ET_o versus estimated alfalfa reference ET_r in open field on weekly basis.

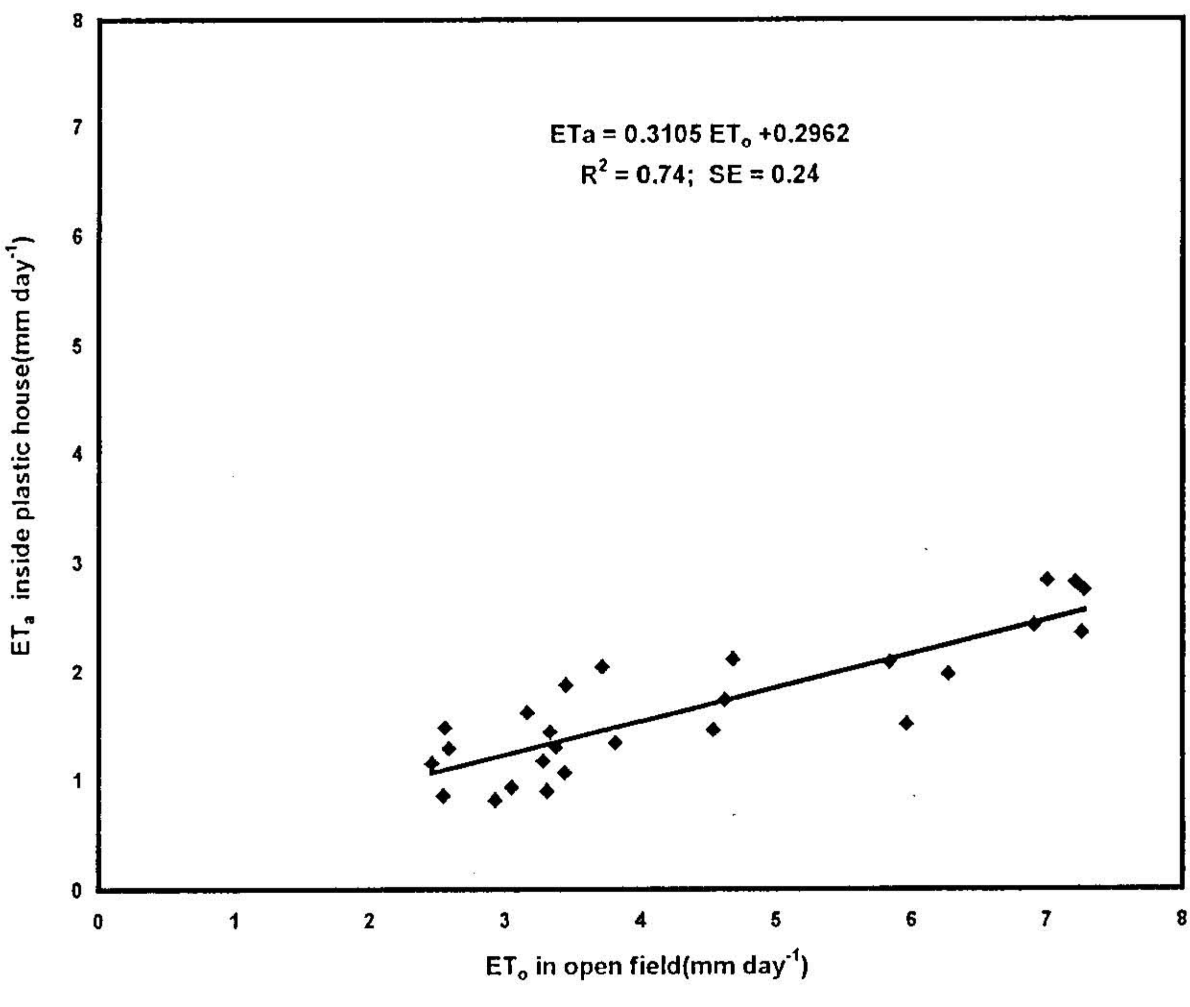


Figure 18. Average daily measured grass reference ET_a inside a plastic house versus estimated grass reference ET_o in open field on weekly basis.

related to ET_0 by: 0.3105 ET_0 +0.2966, $R^2 = 0.74$. For the entire data set, total ETa = 326.23 mm compared to ET_0 = 863 mm, so that on the average, grass reference Eta was 38% of grass reference ET_0 in open fields. This large difference between ET values was mainly due to climatic factors like wind speed, temperature, solar radiation and air relative humidity variations between inside the plastic houses and open field. The plastic house resulted in microclimate conditions where the wind speed effect was very low and the relative humidity was high in addition to the lower solar radiation when compared to the open field. Figure (19) shows average daily estimated alfalfa reference Eta by depletion method inside a plastic house versus calculated alfalfa reference ET_r using Penman-Monteith equation in open fields on a weekly basis. The daily Eta is linearly related to ET_r by: Eta = 0.1996 ET_r +0.9293, $R^2 = 0.74$. For the entire data set, total Eta = 403.39 mm compared to ET_r = 1093 mm so that on the average, alfalfa reference ETa was 37% of alfalfa reference ET_r in open field. The above results mean that plastic houses reduce ET values to about 37-38% of its value in open fields. This reduction is due to three reasons: First, relative humidity inside plastic houses is higher than that in open fields, which reduces the vapor pressure deficit (VPD) and consequently reduced the transpiration rate; Second, incident solar radiation (Rs) inside plastic houses was lower than that at open field, plastic material prevented about 41 to 57 % of Rs from passing through,

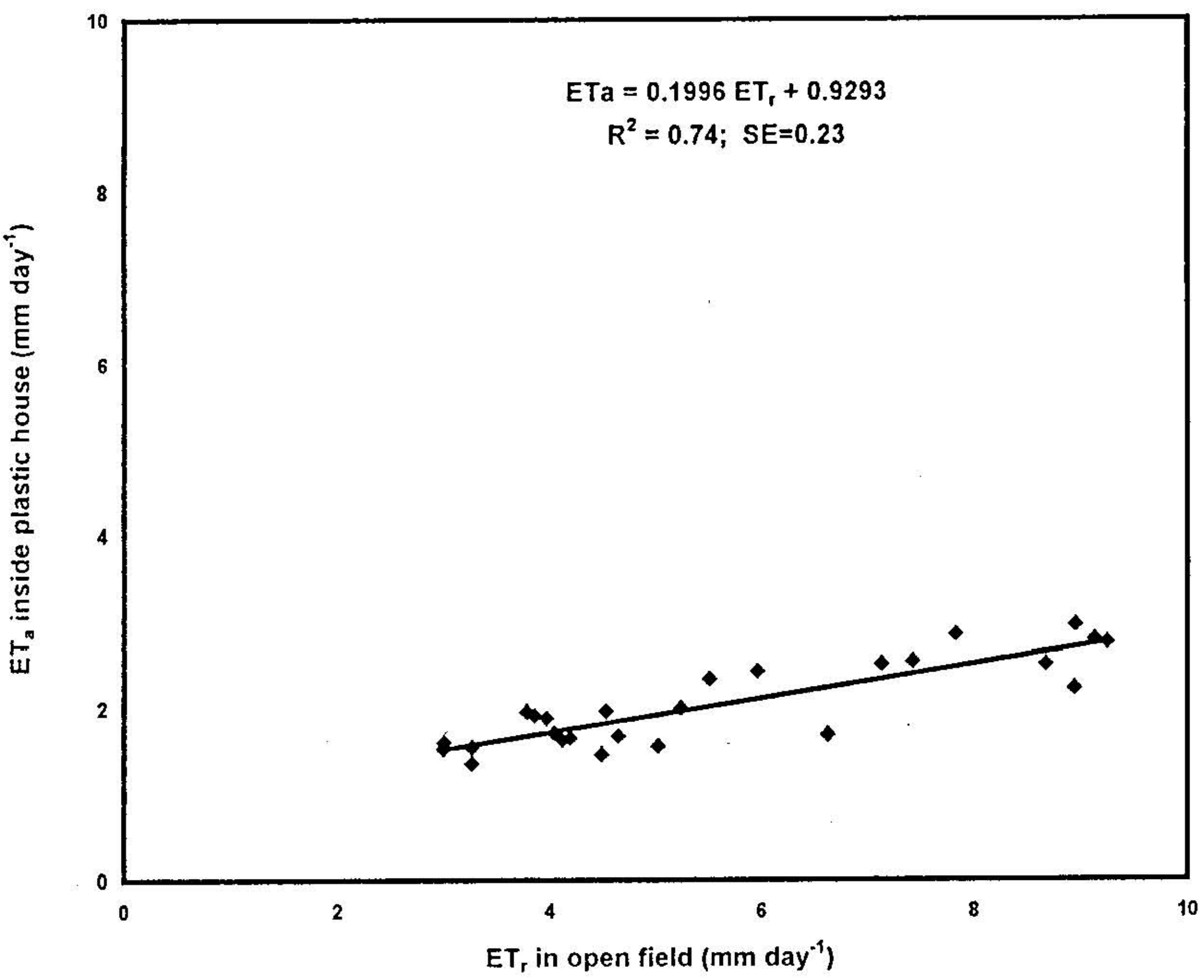


Figure 19. Average daily culculated alfalfa reference ET_a inside a plastic house versus estimated alfalfa reference ET_r in open field on weekly basis.

which reduced ET values; Third, wind speed (U) in plastic houses is very low, compared to that of the open field. This raised the RH inside it, and reduced the ET values. In open field the high wind speed played a major role in rising the ET values by decreasing the aerodynamic resistance (r_a) values. The obtained relationships between measured ET values inside plastic houses and calculated ET values using Penman-Monteith equation in open field can be utilized in irrigation scheduling under plastic house condition by using the calculated ET values in open field (Fig 18 or 19) and the Kc values for selected crops planted inside plastic houses.

4-8. Estimation of evapotranspiration (ET) using Penman-Montieth equation and modeling r_s values inside the plastic houses.

The Penman-Montieth equation (Eq. 4) was used to calculate ET values for grass, alfalfa, tomato and cucumber planted inside plastic houses using r_a = 200 s m^{-1} as assumed (Stanghellini, 1987) and minimum resistance (r_{Lmin}) value was assumed to be equal to r_s calculated from the lowest weekly value of back calculated r_s from P-M model (Maria *et al.* 1994). The minimum resistance (r_{Lmin}) for grass, alfalfa, tomato and cucumber were 408.41, 208.6, 303.64 and 233.51 s m^{-1}, respectively. Recalling the difference between r_s (back calculated from Eq.18) and r_c (Eq.19) is the crop structural resistance (r_o). The linear relations between r_o

and crop height (hc) for grass, alfalfa, tomato and cucumber were obtained (Table 9). Table 10 shows the linear regression for VPD effects on r_L. Results of ETo estimations for grass are shown in Figure (20). Figure (20) shows much better ET_0 estimates when r_c is used only (ETP-M1). Using the ETP-M1 caused over-estimation of ET_0 compared to 1:1 fit line, but it has the lowest SE (0.42 mm day^{-1}) and the higher r^2 (0.82) values. There is no improvement of ET_0 estimates by including r_0 (ETP-M2) or r_{Lmin} adjustment factor for VPD (ETP-M3) for grass inside the plastic houses. While the inclusion of r_0 into r_s term improved the performance of the Penman-Montieth model for grass to be close to 1:1 fit line with lower R^2 values.The results of ET_r estimations for alfalfa are shown in Figure (21) The better ET_r estimates when using ETP-M1 ($R^2 = 0.79$) but with over-estimation of ET_r compared to 1:1 fit line. There is some additional improvement by including r_{Lmin} adjustment factor for VPD (ETP-M3) that reduced the standard error (SE) to 0.26 mm day^{-1}. The estimation of ET for tomato inside the plastic house assuming $r_a = 200$ s m^{-1}, and r_{Lmin} = 303.64 sm^{-1} without including r_0 values (ETP-M1) shows over-estimation by 47% with low R^2 =0.55 and high SE (0.75 mm day^{-1}). While it is much better ET estimates when r_s includes the r_0 component (ETP-M2) with R^2 =0.92 and SE= 0.34 (Fig. 22) . Ignoring the r_0 component caused severe over-estimation of ET. Results of cucumber are similar to that of tomato

Table 9. Relationships of additional surface resistance (r_o) and crop height (hc) for grass, alfalfa, tomatoes and cucumbers grown under plastic house conditions.

crop	Linear equation	R^2
grass	$r_0 = 1961.5$ hc	0.52
alfalfa	$r_o = 881.44$ hc	0.79
tomatoes	$r_o = -686.95$ hc + 2056.2	0.66
cucumbers	$r_o = -546.02$ hc + 1581.6	0.89

hc= m, r_o= m s^{-1}

Table 10. Relationships of vapour pressure deficit adjustment factor of leaf resistance (*f*VPD) and vapour pressure deficit (VPD) for grass, alfalfa, tomatoes and cucumbers grown under plastic house conditions.

crop	Linear equation	R^2
grass	*f*VPD = 1.0877 VPD – 0.1682	0.72
alfalfa	*f*VPD = 1.2555 VPD – 0.4569	0.62
tomatoes	*f*VPD = 3.6016 VPD – 6.9192	0.88
cucumbers	*f*VPD = 1.8835 VPD – 1.347	0.74

***F*VPD = kPa**

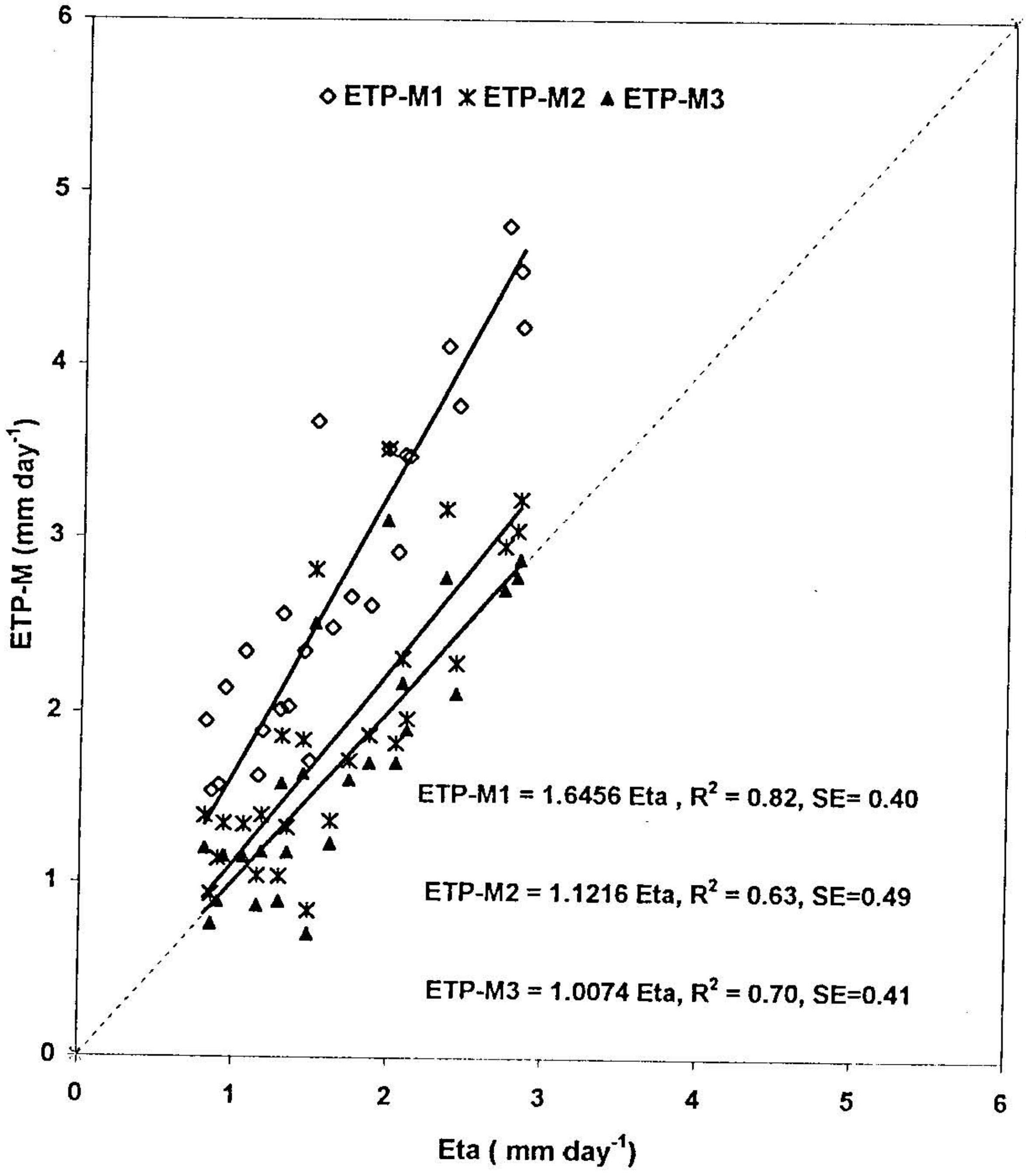


Figure 20. Comparison of measured Eta and estimated ETP-M on weekly basis for grass inside plastic houses.

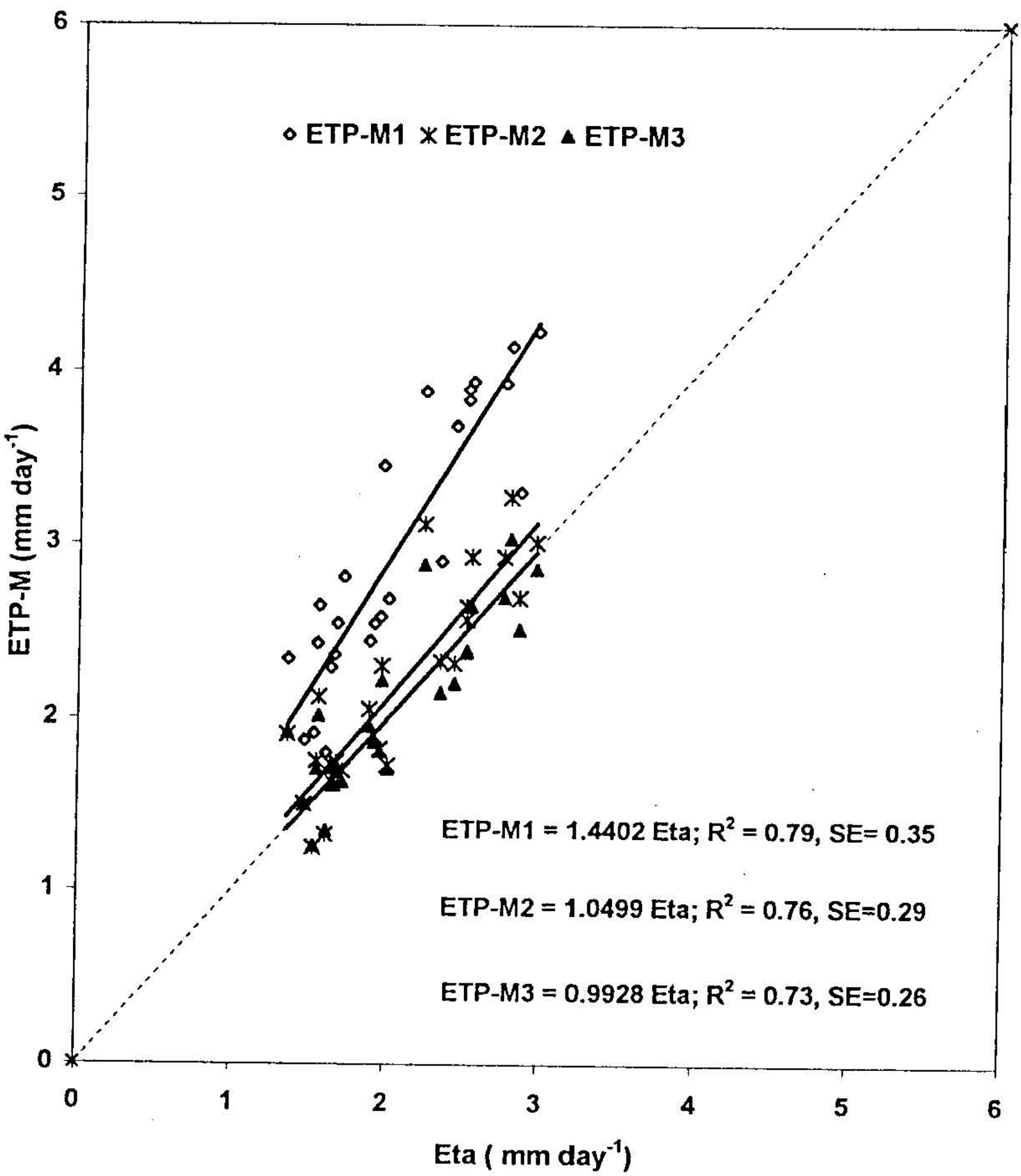


Figure 21. Comparison of measured Eta and estimated ETP-M on weekly basis for alfalfa inside plastic houses.

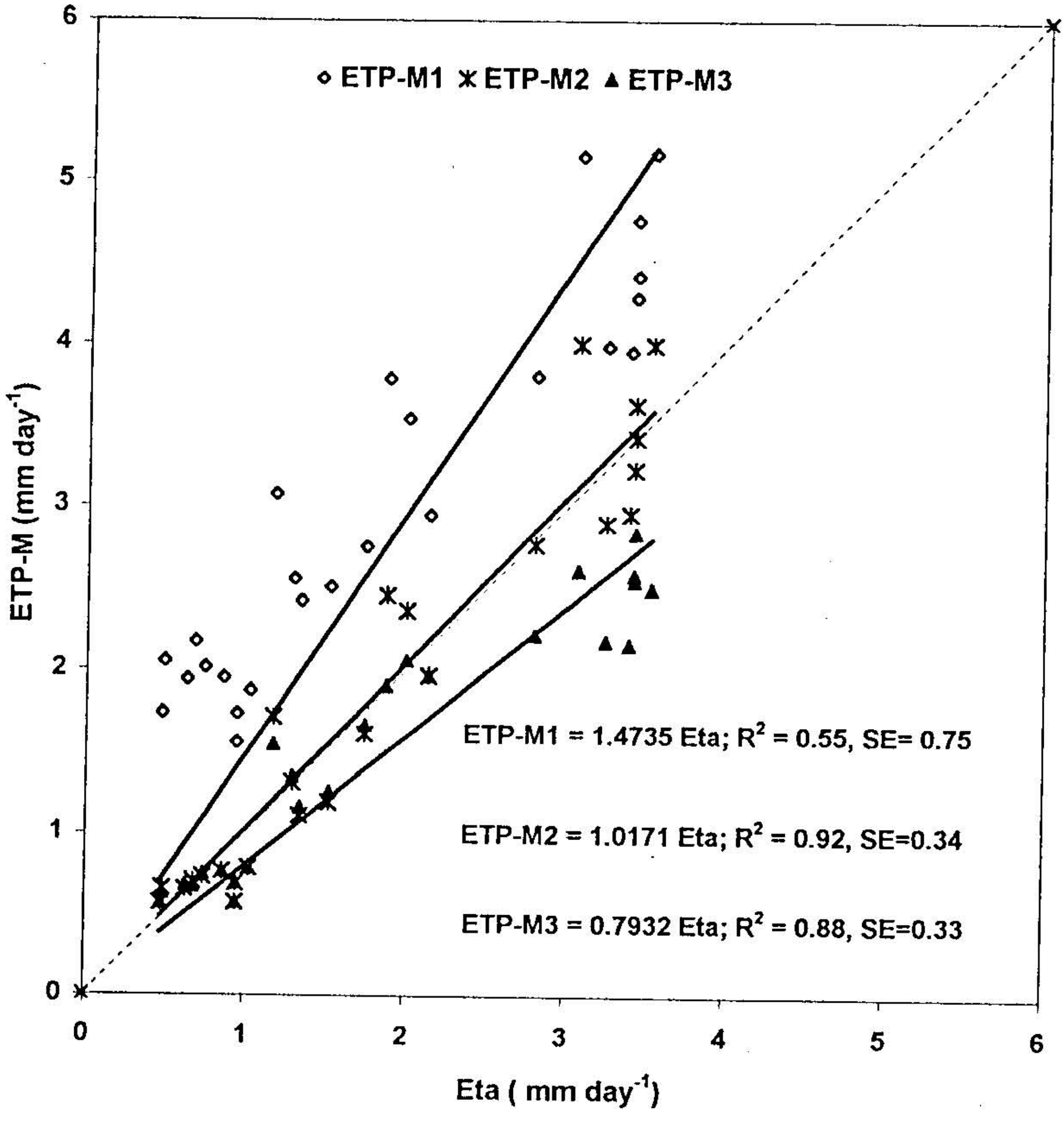


Figure 22. Comparison of measured Eta and estimated ETP-M on weekly basis for tomatoes inside plastic houses.

ET estimations are shown in Figure (23). The estimation of ET for cucumber inside the plastic house assuming $r_a = 200$ s m^{-1}, and $r_{Lmin} =$ 233.51 sm^{-1} without including r_o values (ETP-M1).

The use of adjusted r_{Lmin} for tomato and cucumber actually reduced the accuracy of the ET estimation (Fig. 22 and 23), so it is enough to include r_o only in ET estimations of these crops.

Possible explanations for this result include error in estimation of r_a (assumed r_a = 200 s m^{-1}). Better results could have been expected if accurate r_a and r_{Lmin} had been used. The actual values of r_a and r_{Lmin} were determined for the four crops in the following section (4-9).

4-9. Prediction of potential evapotranspiration inside plastic houses using the model based on Penman-Monteith equation.

The parameters *A* and *B* for the model (Eq.25) have been determined for the four crops from statistical regression between evapotranspiration rate and both Rn and VPD. The statistical parameters (Steel and Torrie, 1980) used to determine the goodness of fit were:

1. Coefficient of determination R^2, defined as 1-(RSS/CSS), where RSS is the residual sum of squares and CSS is the corrected sum of squares (or the variance of the original data set about its mean);

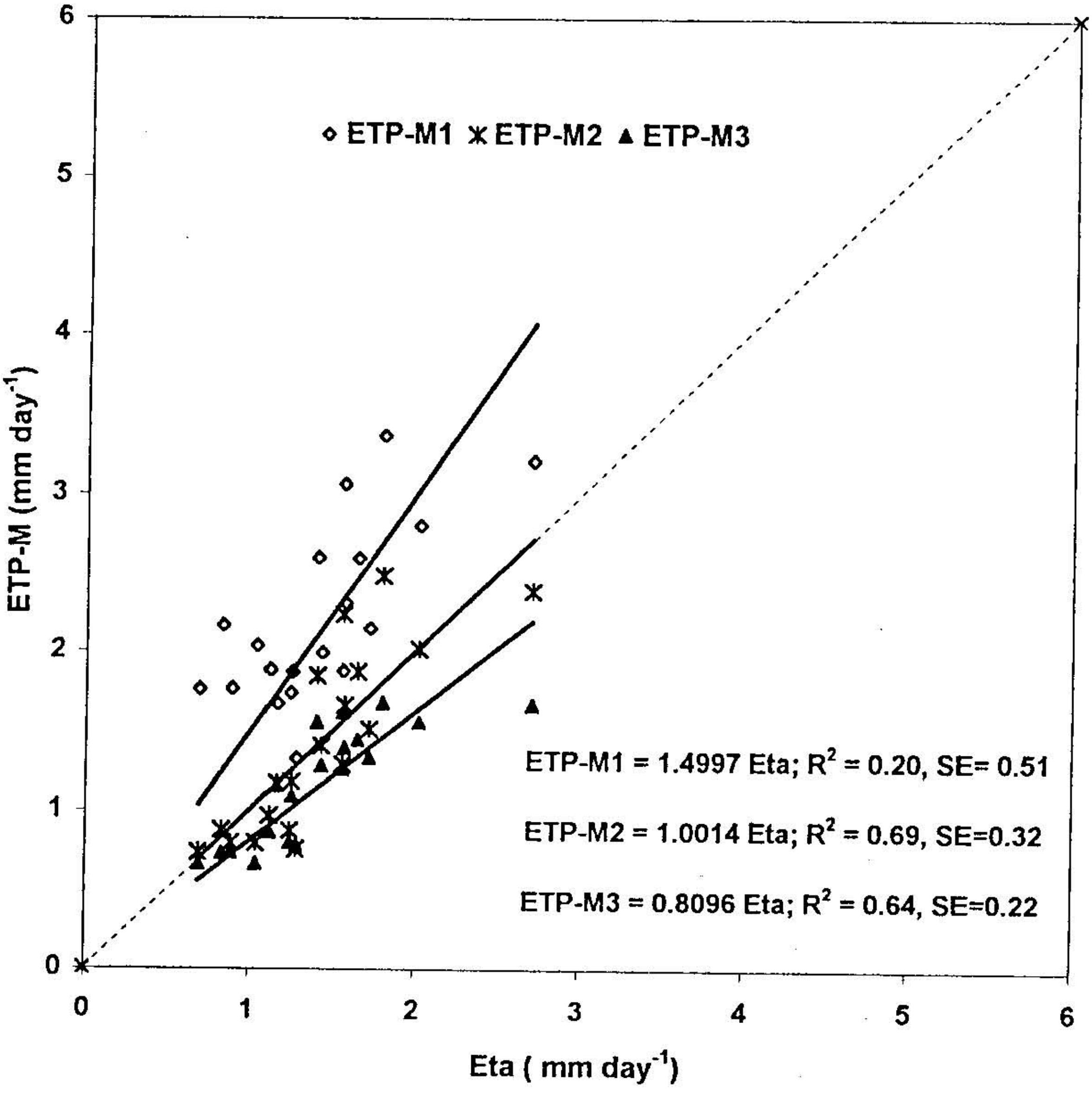


Figure 23. Comparison of measured Eta and estimated ETP-M on weekly basis for cucumbers inside plastic houses.

2. Standard error of the model (SE) defined as the square root of RSS/(number of data points minus number of model parameters).

4-9-1. Coefficients, *A* and *B*

Table 11 present the values of *A* and *B*, standard error (SE) and R^2 obtained from the statistical regression using Eq. (25) for the four crops. The highest value of R^2 was for cucumber (0.95) followed by R^2 for tomato (0.89). From Table 11, *A* and *B* values differ according to the crops, where: *A* ranges from 0.1344 (Alfalfa) to 0.2979 kg MJ^{-1} (Tomato); *B* ranges from 0.1589 (Tomato) to 0.7691 $kgm^{-2}day^{-1}kaP^{-1}$ (Alfalfa). These variations reflect primarily the sensitivity of the crops to two environmental variables, Rn and VPD. In particular, high value of *B* (Alfalfa) reflect the greater response of the transpiration rate to saturation vpour pressure deficit.

4-9-2. Partition between the radiation and advective terms

Numerical examples (Appendix 2, example 3) of average daily on weekly basis rates of ET from Eq. (25) are presented in Table 12. with Rn= 8.64 KJ m^{-2} day^{-1} and VPD = 2 kPa. Values of ET range from 2.13 kg $m^{-2}day^{-1}$ for grass to 2.89 kg m^{-2} day^{-1} for tomatoes. The 'radiative' term (*A* Rn) contribution about 77, 43, 89, and 81 % to the evapotranspiration rate for grass, alfalfa, tomato, and cucumber, respectively. While the

Table 11. Parameter values (*A* and *B*), standard error (SE) and coefficient of determination (r^2) of the model from fitting ET data with equation (25).

crops	*A*[a]	B[b]	SE[c]	r^2
Grass	0.1889	0.2492	0.28	0.77
Alfalfa	0.1344	0.7691	0.30	0.67
Tomato	0.2979	0.1589	0.40	0.89
Cucumber	0.2510	0.2555	0.06	0.95

[a] Expressed in kg MJ^{-1} [b] Expressed in kg $m^{-2}day^{-1}$ kPa^{-1}

[c] Expressed in kg $m^{-2}day^{-1}$

Table 12. Average daily on weekly basis rates of ET and partition between radiative and advective components, calculated using Eq. (25) for Rn = 8.64 MJ day^{-1} m^{-2} and VPD=2kPa.

	ET Kg m^{-2} day^{-1}	Radiative part %	Advective part %
Grass	2.13	76.61	23.39
Alfalfa	2.70	43.02	56.98
Tomato	2.89	89.01	10.99
Cucumber	2.71	80.93	19.07

'advective' term (B VPD) contribute about 23, 57, 11, and 19 % to ET for the same respective crops. The following conclusions can be drawn from Table 12:

1- Crops like tomato represents high level of evapotranspiration rate, about 90% of its ET from the use of incident radiation (energy) on the crop. While the contributions of advective part to ET values of alfalfa was low being 57%. This means that reducing VPD from 2 to 1 kPa, the ET decreased from 2.7 to 1.93 kg $m^{-2}day^{-1}$. These characteristics influence the energy and water status inside of plastic house, as evapotranspiration is the main source of water and the main cooling process of the plant.

2- Values of A and B coefficients suggest that the effect of climate control devices such as shading or fog-system (Maria *et. al*, 1994) can be quite different according to the crops. For crops with high values of A (tomato and cucumber), a shading screen (decrease solar radiation) will reduce the ET values. For this reason some farmers at the Jordan Valley shade their plastic houses by clay (specially during May).

4-9-3. Analysis of model parameters.

4-9-3-1. Parameter *A*

If we consider A (Eq. 27a) as an approximate average value of the of the ratio $\Delta/\lambda(\Delta + (1+r_s/r_a))$ in weekly basis, we can deduce the order of magnitude of the ratio r_s/r_a from:

$$\frac{r_s}{r_a} = \left[\frac{\Delta}{\lambda\gamma}\left(\frac{1-\lambda A}{A}\right)\right] - 1 \qquad (42)$$

Assuming air temperature 25 °C so =1.22 k Pa °C^{-1}, = 2.44 MJ kg^{-1}, and =0.07 k Pa °C^{-1}, then values for r_s/r_a vs. A (Appendix 2, example 4):

$A = 0.299$ $r_s/r_a = 0$

$A = 0.29$ $r_s/r_a = 0.1$

$A = 0.24$ $r_s/r_a = 1$

$A = 0.1$ $r_s/r_a = 5$

$A = 0.08$ $r_s/r_a = 10$

The ratio of r_s/r_a for the four crops is given in Table 13.The theoretical maximum value of A is 0.299 for $r_s/r_a = 0$. For A = 0.29, $r_s/r_a = 0.1$. This value implies that crops showing A values of about 0.29 (e.g tomato) have low values of r_s compared with r_a. This means that r_a of tomato has the larger effect on r_s/r_a ratio, so accurate calculation of r_a will improve ET estimation. The smallest r_s value (15 s m^{-1}) was for tomato plant because it have high LAI (4.98) and growth rate so leaf stomata has to be opened to introduce CO_2 gas for longer time to be used it in photosynthesis process, thus evaporation from open stomata increased. The r_a is inversely affected by wind speed (Eq. 6), so the high r_a value (1059 s m^{-1}) was due to very low wind speed inside the plastic house in addition to the plant height (2.5 m) and high LAI of tomato which is reduced to its lowest value. With cucumber an intermediate values of A, about (0.22 to 0.25)and r_s/r_a 1 ,

Table 13. The ratio r_s / r_a, r_s (leaf stomatal resistance) and r_a (leaf aerodynamic resistance) values as calculated from Eq. (42 and 43), with the values of *A* and *B* from Table 11.

Crop	r_s / r_a	r_a ($s\ m^{-1}$)	r_s ($s\ m^{-1}$)
Grass	2.16	428	924
Alfalfa	4.53	99	448
Tomato	0.01	1059	15
Cucumber	0.71	555	393

means that r_s has about the same value of r_a. So these values have the same effect on estimation of ET. The r_a of cucumber was 555 s m^{-1} (Table 13) lower than that of tomato. Because cucumber's height (2.25 m) and LAI (2.3) and are lower than that of tomato (height = 2.5m, LAI = 5.98), and consequently wind movement is easier and higher, so lower r_a value was obtained (Eq. 8). The r_s value of cucumber was higher than that of tomato because cucumber plant has lower LAI and height, so photosynthesis rate is lower and the stomata opening time is shorter. In addition to that, cucumber reached the harvesting date earlier than that of tomato by 45 days which is the warmest period in the growing season. So, VPD for cucumber, was lower. The lowest value of A (0.1344 for alfalfa, and 0.1889 for grass) suggest that r_s is greater than r_a for these crops. The r_a values were 99 and 428 s m^{-1} for alfalfa and grass, respectively. These are considered low values when compared with tomato's and cucumber's r_a values. Because, the tomato and cucumber heights are much more than that for grass and alfalfa. Therefore wind movement is high and r_a values are lower. Grass and alfalfa have high r_s values of 924 and 448 sm^{-1}, respectively. (Table 13) that of tomato. Because cucumber's height (2.25 m) and LAI (2.3) and are lower than that of tomato (height = 2.5m, LAI = 5.98), and consequently wind movement is easier and higher, so lower r_a value was obtained (Eq. 8). The r_s value of cucumber was higher than that of tomato because cucumber plant has lower LAI and height, so photosynthesis rate is lower and the stomata opening time is shorter. In addition to that, cucumber reached the harvesting date earlier than that of tomato by 45 days which is the warmest period in the growing season. So, VPD for cucumber, was lower. The lowest value of *A* (0.1344 for alfalfa, and 0.1889 for grass) suggest that r_s is greater than r_a for these crops. The r_a values were 99 and 428 s m^{-1} for alfalfa and grass, respectively. These are considered low values when compared with tomato's and cucumber's r_a values. Because, the tomato and cucumber heights are much more than that for grass and alfalfa. Therefore wind movement is high and r_a values are lower. Grass and alfalfa have high r_s values of 924 and 448 sm^{-1}, respectively. (Table 13) when, compared to their theoretical values in the open field (70 and 45 s m^{-1}). This large variation in r_s value is due to low wind speed and high air relative humidity (RH) inside the plastic houses, that caused thick boundary layer around the leaves, which contributes to decreasing the vapour pressure deficit. While at outside condition the RH is lower due to continuus air movement closed to the plant leaves. This, in turn, cause thinner leaf boundary layer, where r_s values decrease.

4-9-3-2. Parameter *B*

For each crop, an estimate of r_a can be deduced from the values of *B* as follows:

$$r_a = \frac{1}{\lambda B}\left[\frac{86.4\rho c_p}{\Delta + \gamma(1+\frac{r_s}{r_a})}\right] \qquad (43)$$

The values of Δ, ρ, and c_p values at 25 °C are 0.189 kPa $°C^{-1}$, 1.22 kg m^{-3}, and 1.013 KJ kg^{-1} $°C^{-1}$, respectively. Then using Eq. (31 and 25a):

$$r_a = \frac{1}{\lambda B}\left[\frac{86.4\rho c_p}{\Delta + \gamma(1+\frac{r_s}{r_a})}\right] = \frac{1}{\lambda B}\left[\frac{86.4\rho c_p}{\frac{\Delta}{\lambda A}}\right] = \frac{A}{B}\left[\frac{86.4\rho c_p}{\Delta}\right] = \frac{A}{B}\left[\frac{86.4*1.22*1.013}{0.189}\right]$$

$$r_a \approx 565\frac{A}{B} \qquad (44)$$

The calculated r_a values (Eq.43) are given in Table 15. These values of r_a vary from about 99 s m^{-1} (alfalfa) to 1059 sm^{-1} (tomato). Thus it is possible to estimate the magnitude of the leaf stomatal resistance r_s from the calculated values of ratio r_s / r_a. The values of calculated r_a inside the plastic houses are relatively high compared to those of open field, because wind speed inside the plastic houses is very low.

4-9-4. Test the validity of using the obtained r_a and r_s values in Penman-Monteith equation inside plastic houses.

Penman-Monteith equation (Eq. 4) was used to calculate ET in the four plastic houses using r_a and r_s as predicted from the previous model in Table 13. The periods chosen for this process were different from those used for establishment of the model in Eq. 25. Results of comparisons between predicted ET (ETP-M) using Penman-Monteith equation and measured values by depletion method using TRIME (Eta) are presented in Figures 24, 25, 26 and 27 for grass, alfalfa, tomatoes and cucumbers, respectively. Linear regression analysis was preformed on weekly estimates with ET measured by depletion method as dependent variable and ETP-M estimate as independent variable. Regression through the origin was selected to evaluate the goodness of fit between ETP-M equation estimates and actual ET measurements. The agreement is quite satisfactory for all crops (the slope 1) with standard error of (0.19, 0.21, 0.32 and 0.36 mm day^{-1}) and R^2 of (0.93, 0.86, 0.91 and 0.51) for grass, alfalfa, tomato and cucumber, respectively. The results show that goodness of fit for cucumber (Fig. 27) was less than those for the other three crops. The reason was that cucumber has a high sensitivity to diseases, ventilations process was done to decrease air relative humidity from time to time to ovoid the occurrence of deseases, by opening small spaces between the plastic house sheets. The comparisons presented in Figures (24, 25, 26 and 27) indicate that using a constant values for r_s and r_a (Table 13) appears to be valid for predicting ET for the crops used in this study during weekly time periods

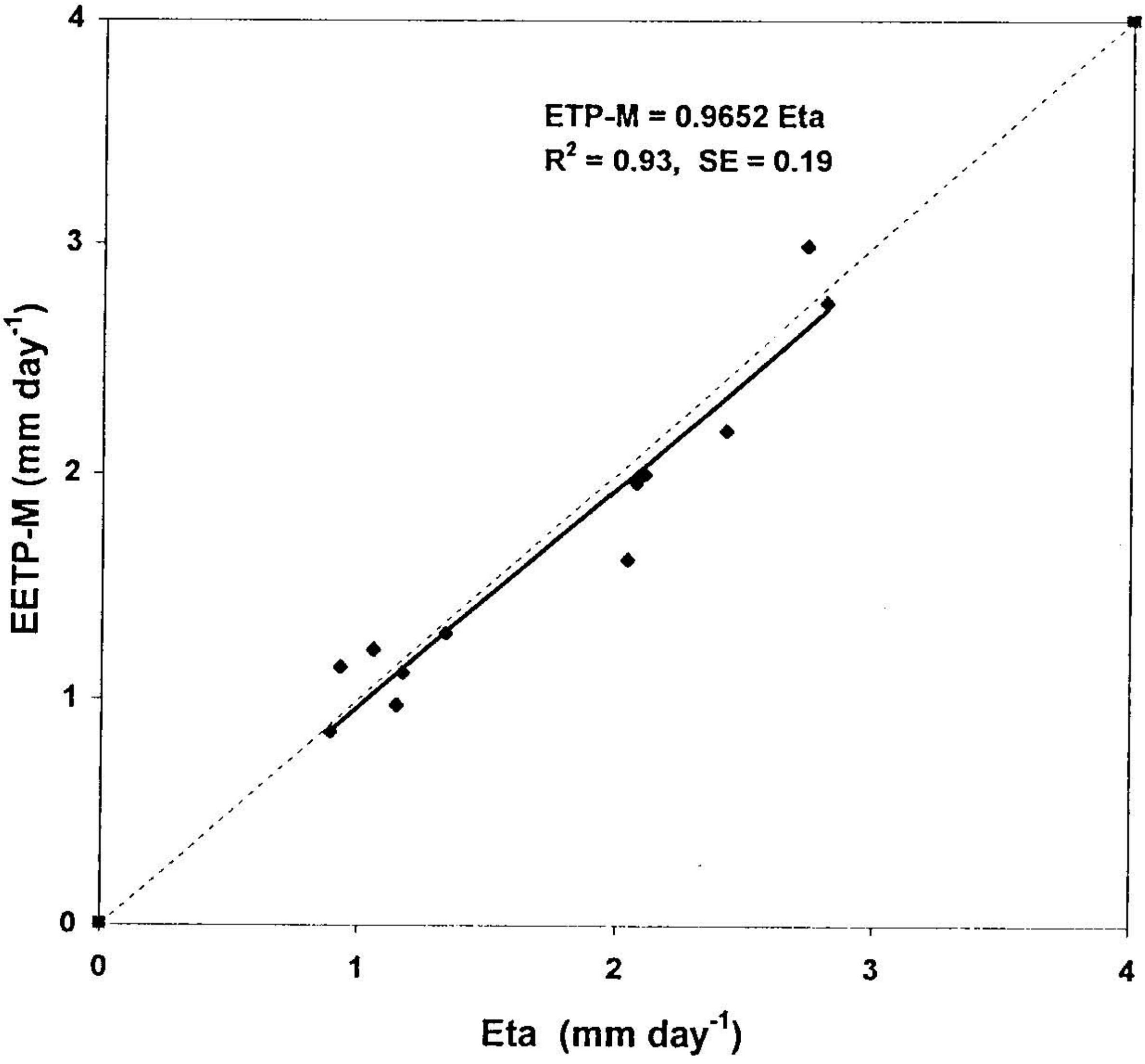


Figure 24. Comparison of measured Eta and calculated ETP-M using Penman-Monteith model on a weekly basis for grass under plastic house conditions.

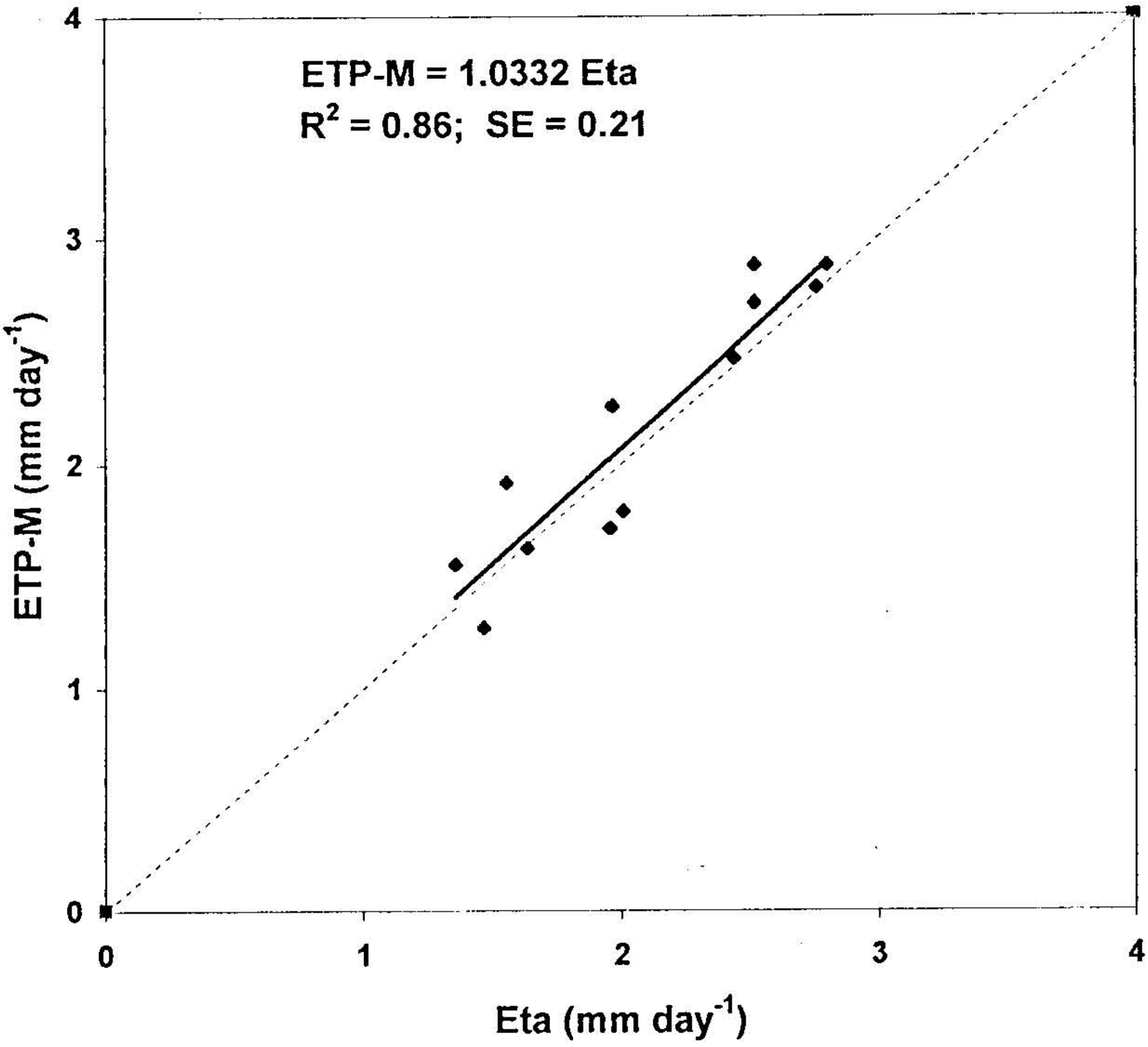


Figure 25. Comparison of measured Eta and calculated ETP-M using Penman-Monteith model on a weekly basis for alfalfa under plastic house conditions.

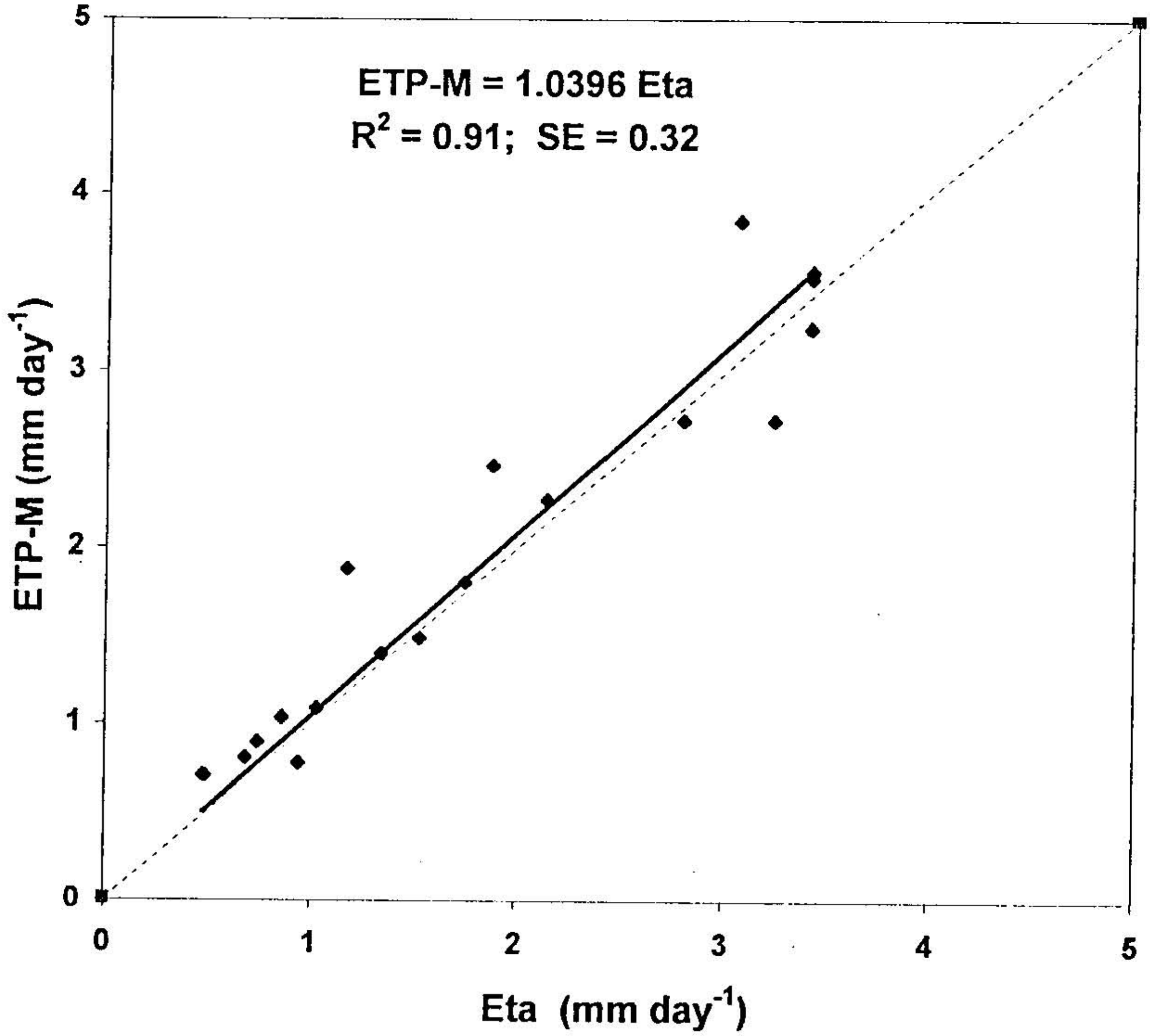


Figure 26. Comparison of measured Eta and calculated ETP-M using Penman-Monteith model on a weekly basis for tomatoes under plastic house conditions.

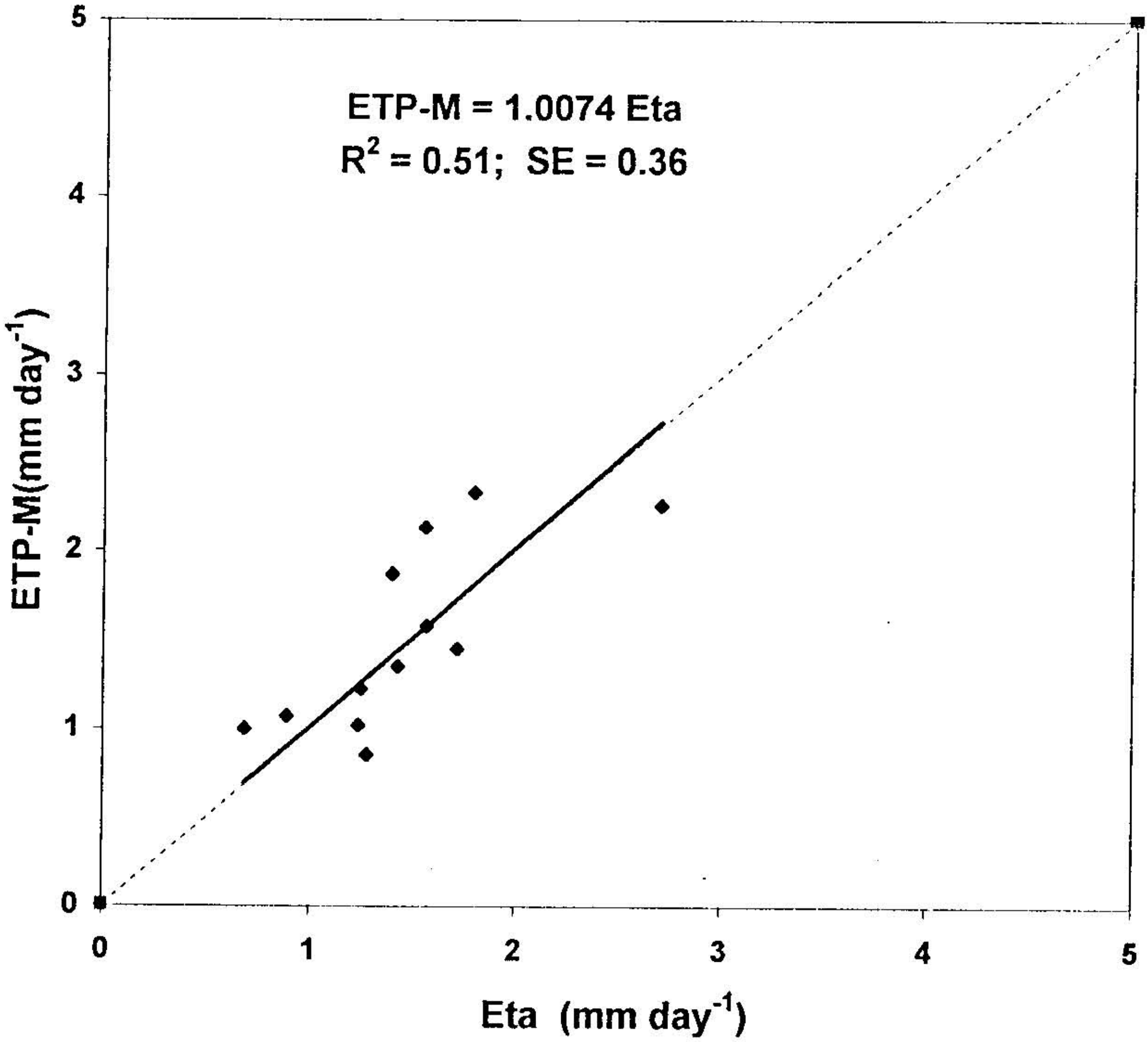


Figure 27. Comparison of measured Eta and calculated ETP-M using Penman-Monteith model on a weekly basis for cucumbers under plastic house conditions.

under plastic house conditions. While in open field, the constant value of r_s only is recommended for calculating ET and variable r_a as a wind speed function (Allen *et al.*, 1994).

4-9-5. Crop coefficient values for tomato and cucumber inside the plastic houses using Penman-Monteith equation.

The crop coefficient curves were developed in open fields by Allen *et al.* (1998) using Penman-Monteith equation assuming constant crop reference height, surface resistance and LAI. So to obtain like these curves inside the plastic houses we assumed constant crop reference height and using the calculated r_a and r_s values for grass and alfalfa from Table 13. For grass reference crop we used 12 cm plant height, $r_a = 428$ s m^{-1} and $r_s = 924$ s m^{-1} , and for alfalfa reference crop we used 50 cm plant height, $r_a = 99$ s m^{-1} and $r_s = 448$ s m^{-1}. The net solar radiation values (Rn) were calculated from Appendix1,Table 9. The Kc values for tomato and cucumber were calculated by dividing the actual measured evapotranspiration of these crops by the calculated ET values for the reference crops using Penman-Monteith equation inside the plastic houses on weekly basis. Tables 14 and 15 show the Kc values during the phenological growth stages for tomato and cucumber crops, respectively, using the calculated ET values for grass and alfalfa reference crops. The obtained Kc values and the reported FAO values for tomato and cucumber

Table 14. Crop coefficients values for tomato crop using calculated Penman-Monteith reference crops ET inside the plastic houses.

Growth Period	Initial	Crop Devt	Mid-season	Late season
Days	1-38	39-87	88-170	171-198
Kc1 *	0.50	0.92	1.34	1.09
Kc2 **	0.31	0.61	0.91	0.91

* Kc1 = Kc values of tomato inside the plastic houses using grass as reference crop.

** Kc2 = Kc values of tomato inside the plastic houses using alfalfa as reference crop.

Table 15. Crop coefficients values for cucumber crop using calculated Penman-Monteith reference crops ET inside the plastic houses.

	Initial	Crop Devpt	Mid-season	Late season
Growth Period	1-29	30-70	71-128	129-152
Kc1 *	0.67	0.98	1.29	0.97
Kc2 **	0.46	0.64	0.81	0.66

* Kc1 = Kc values for cucumber inside the plastic houses using grass reference crop.

** Kc2 =Kc values for cucumber inside the plastic houses using alfalfa reference.

were presented in Figures (28, 29, 30, and 31). These Kc curves can be used in irrigation scheduling because it have stable values during the phenological stages compared with the measured Kc values (Figures 13, 14, 15 and 16), and they followed the same trend of the reported values in open field. This also was due to using similar reference crops height and LAI in open field and inside plastic houses.

4-10. Potential evapotranspiration using empirical equations

Tables 16 and 17 show the average daily estimated ET values inside grass and alfalfa plastic houses on weekly basis, respectively, using Hargreaves (ET_H), FAO Blaney-Criddle (ET_{B-C}) and Jensen-Haise (ET_{J-H}) methods. The comparison of calculated ET values using these empirical equations and the measured ET values by depletion method inside grass and alfalfa plastic houses are shown in Figures (32 and 33). The reference grass ET estimates using Hargreaves equation (ET_H) and Jensen-Haise (ET_{J-H}) methods were well correlated with actual measurement (ETo) inside the plastic houses with SE and R^2 values of 0.37 mm day^{-1} and 0.78 for ET_H ,and 0.46 mm day^{-1} and 0.77 for ET_{J-H} methods (Fig 32).

The reference alfalfa ET estimates using (ET_{B-C}) method was well correlated with actual measurement (ET_r) inside the plastic houses with SE and R^2 values of 0.50 mm day^{-1} and 0.70, respectively (Fig. 33).While ET_{H-S} has the highest SE of 0.93 mm day^{-1}. The Penman-Montieth method

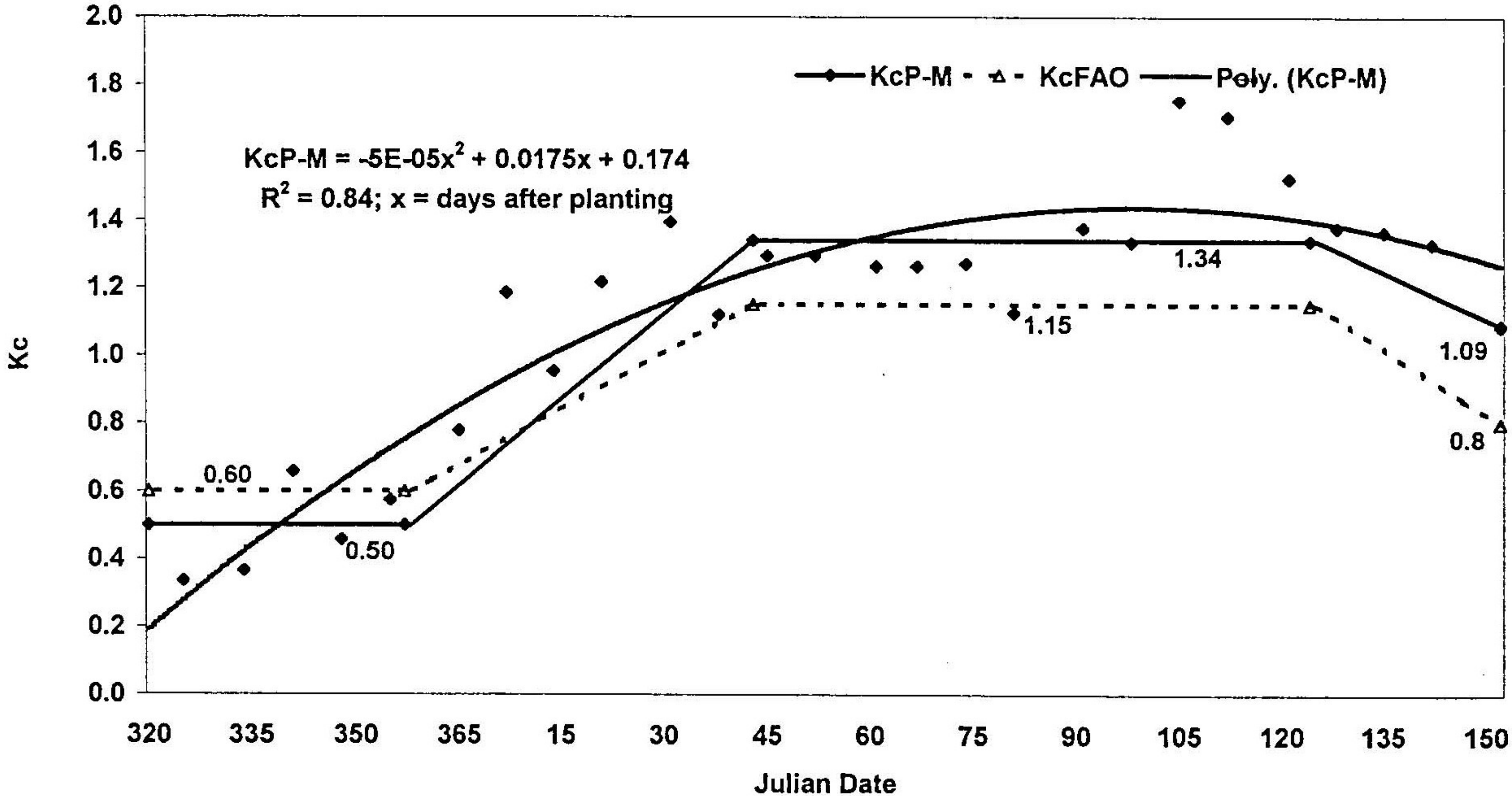


Figure 28. Calculated crop coefficient curve inside the plastic houses using Penman-Monteith equation (Kc_{P-M}) and FAO curve in open field (Kc_{FAO}) for tomato with grass reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

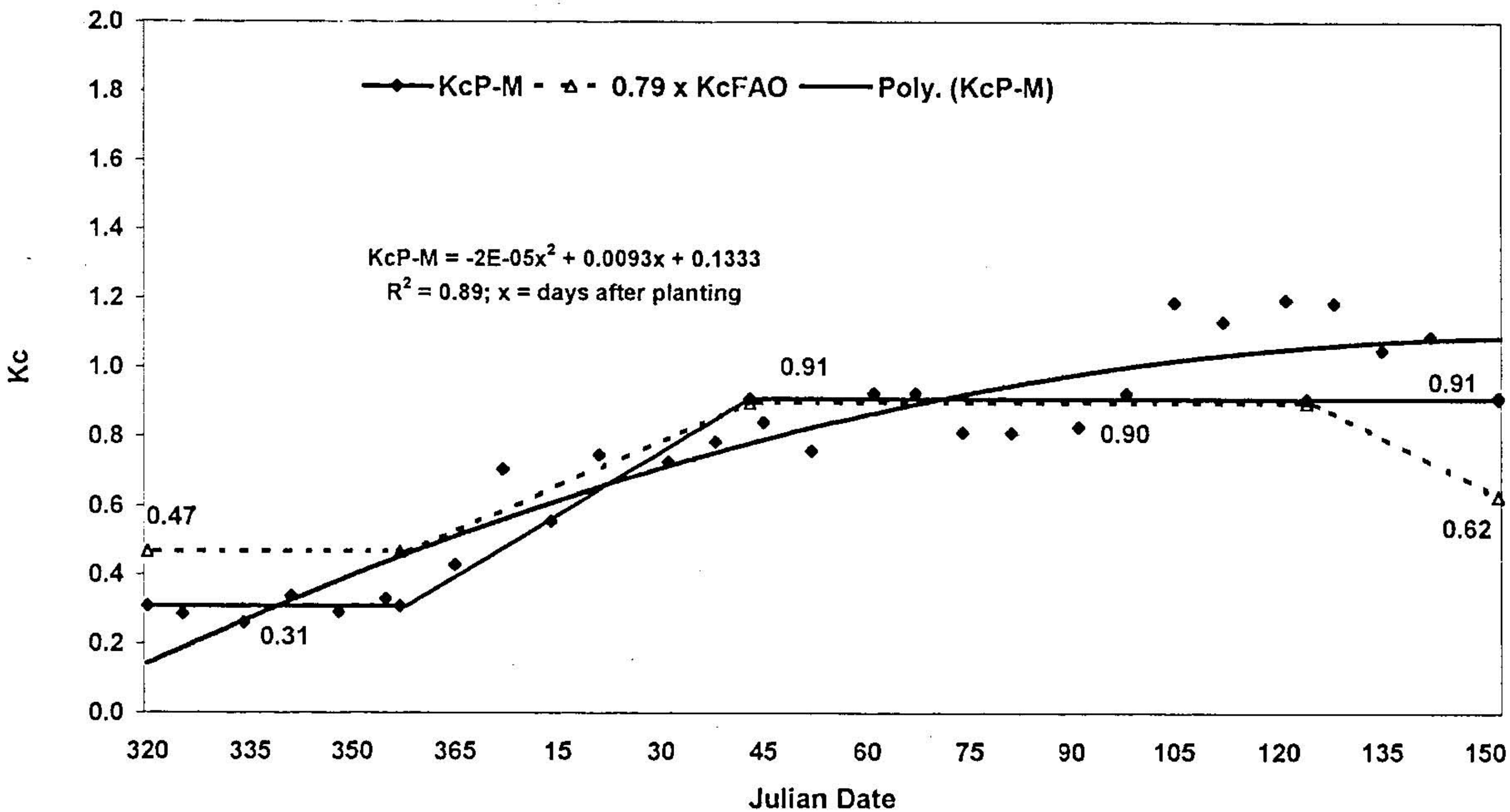


Figure 29. Calculated crop coefficient curve inside the plastic houses using Penman-Monteith equation (Kc_{P-M}) and FAO curve in open field (0.79 x Kc_{FAO}) for tomato with alfalfa reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

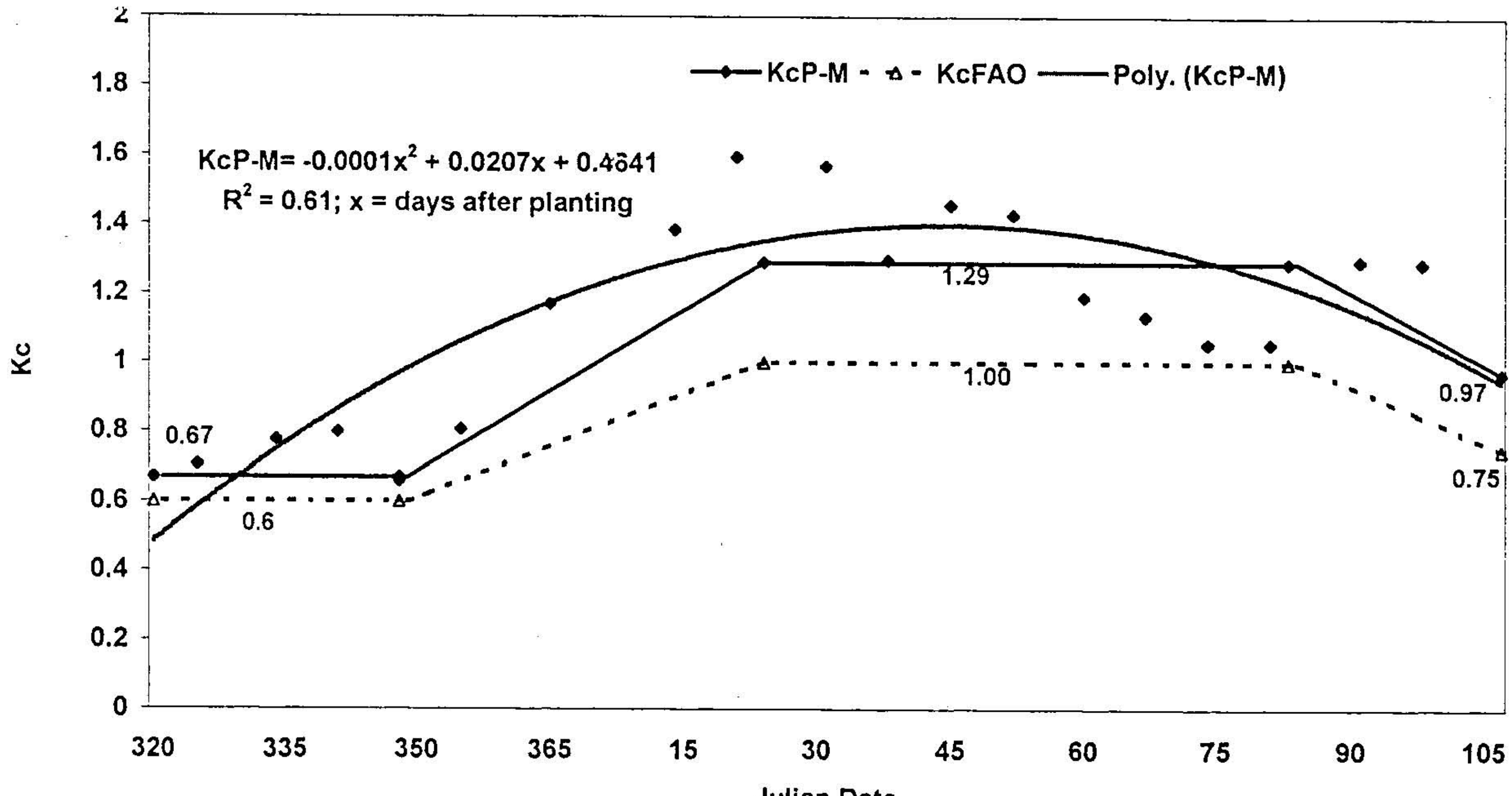


Figure 30. Calculated crop coefficient curve inside the plastic houses using Penman-Monteith equation (Kc_{P-M}) and FAO curve in open field (Kc_{FAO}) for cucumber with grass reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

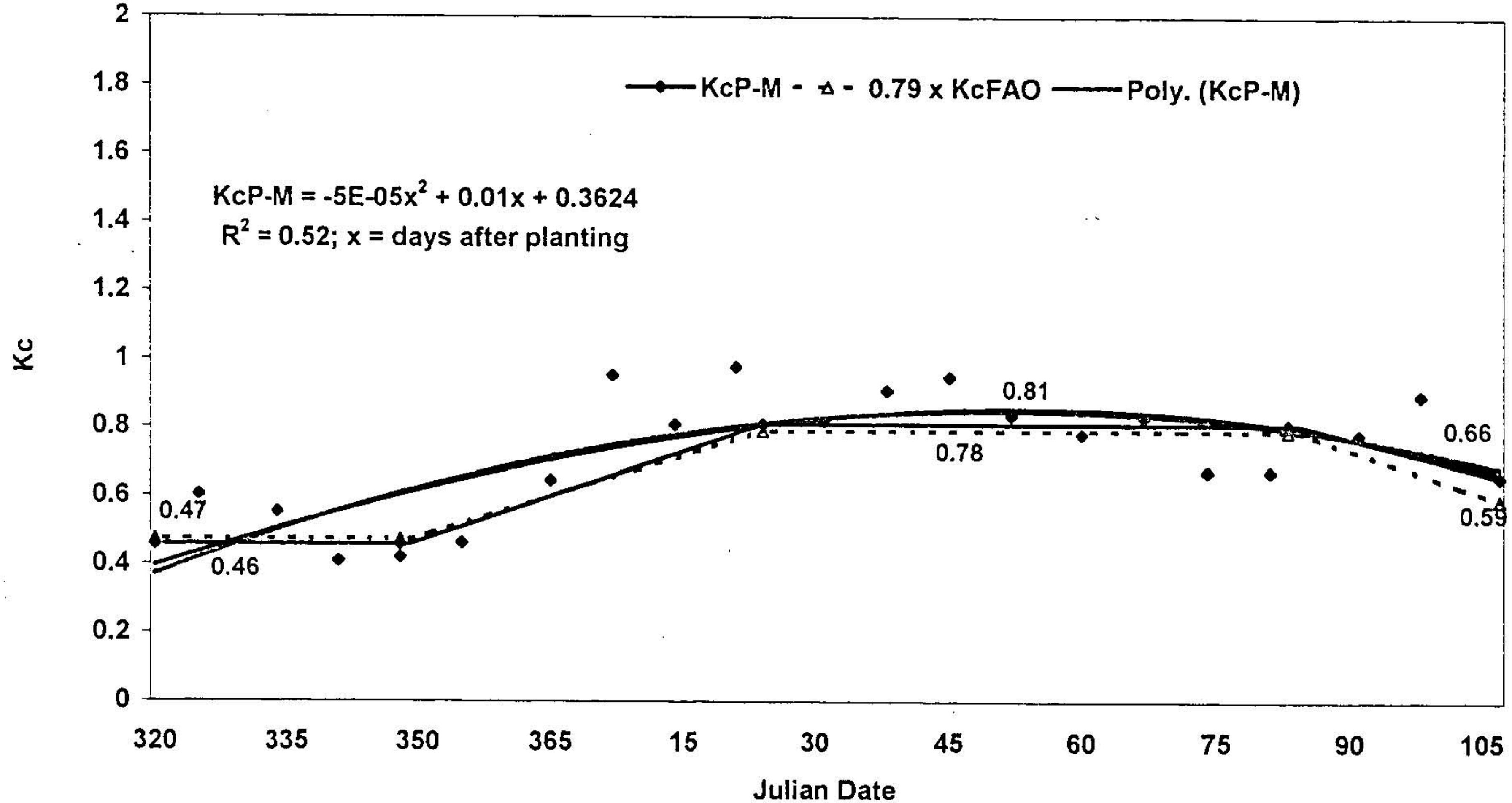


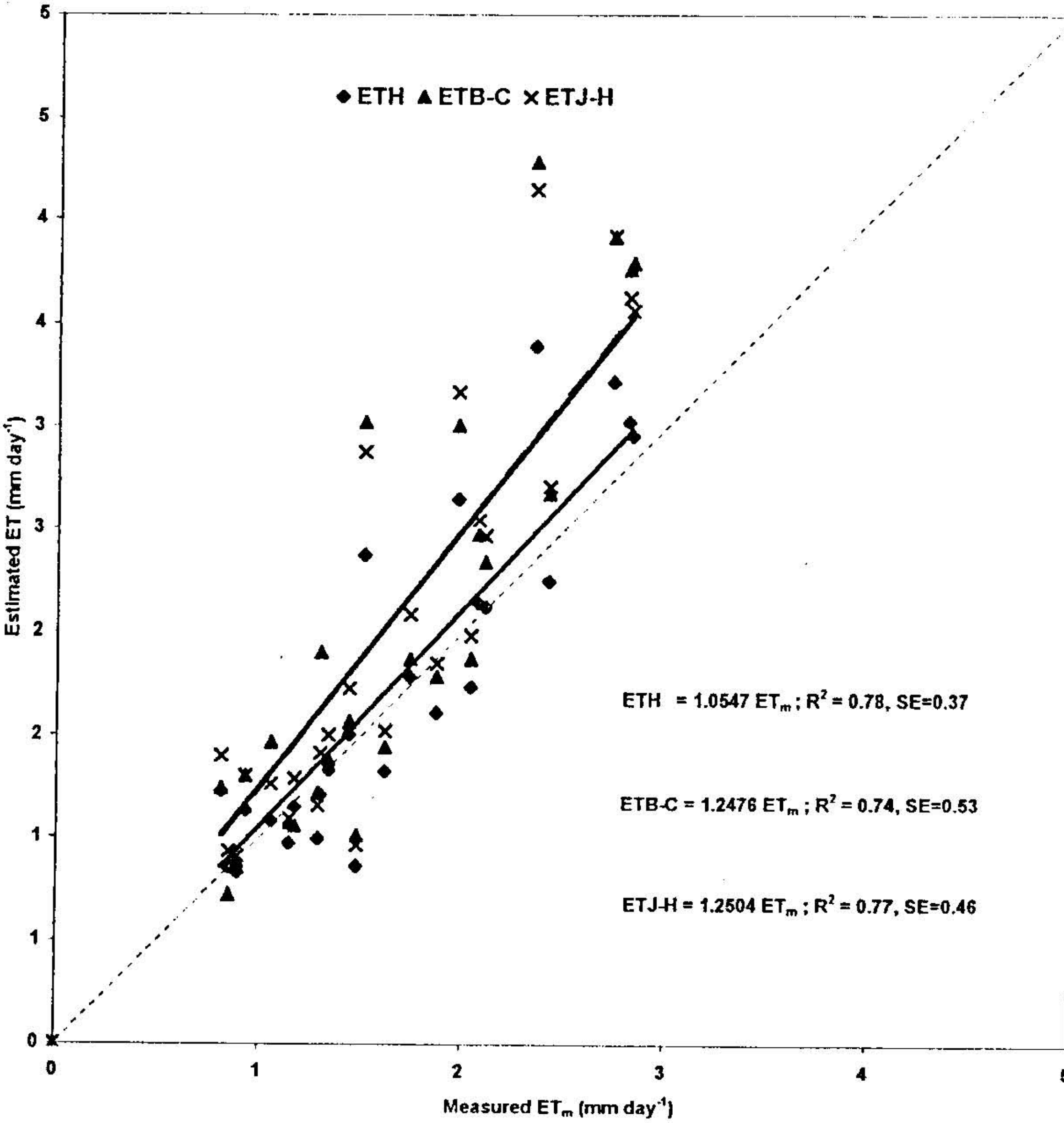
Figure 31. Calculated crop coefficient curve inside the plastic houses using Penman-Monteith equation ($Kc_{P\text{-}M}$) and FAO curve in open field (0.79 x Kc_{FAO}) for cucumber with alfalfa reference crop; 320 and 15 represent the 16 November 1999 and 15 January 2000, respectively.

Table 16. Average daily estimated ET values inside grass plastic house using Hargreaves (ET_H), FAO Blaney-Criddle (ET_{B-C}) and Jensen-Haise (ET_{J-H}) methods on weekly basis inside plastic houses.

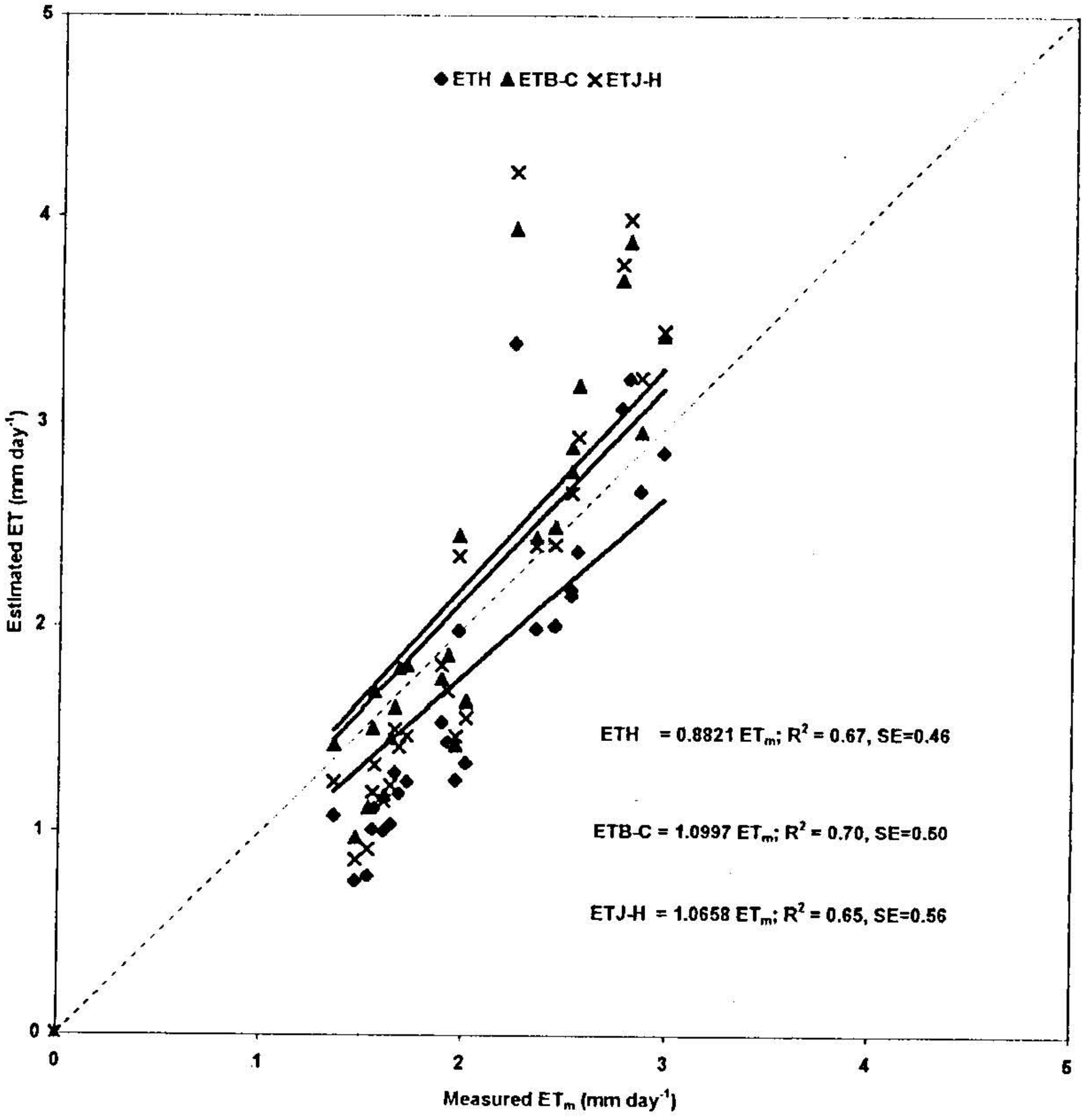
Month	Period	ET_H	ET_{B-C}	ET_{J-H}
Nov	22-30	1.21	1.90	1.34
Dec	1-7	1.22	1.24	1.33
	8-14	1.13	1.30	1.23
	15-21	1.08	1.46	1.20
	22-31	0.99	1.22	1.09
Jan	1-7	0.86	1.01	0.91
	8-14	0.97	1.07	1.03
	15-21	0.82	0.87	0.86
	22-31	0.85	0.72	0.88
Feb	1-7	1.32	1.44	1.44
	8-14	1.33	1.38	1.42
	15-21	1.14	1.05	1.22
	22-29	1.50	1.56	1.63
Mar	1-7	1.61	1.78	1.75
	8-14	1.73	1.86	1.88
	15-21	2.12	2.33	2.33
	22-31	1.78	1.86	1.97
April	1-7	2.37	3.02	2.72
	8-14	2.14	2.47	2.41
	15-21	2.24	2.67	2.56
	22-30	2.64	3.00	3.00
May	1-7	2.95	3.79	3.38
	8-14	3.02	3.76	3.44
	15-21	3.22	3.91	3.71
	22-31	3.39	4.28	3.93
Total (mm)		**334.36**	**390.22**	**373.21**

Table 17. Average daily estimated ET values inside alfalfa plastic house using Hargreaves (ET_H), FAO Blaney-Criddle (ET_{B-C}) and Jensen-Haise (ET_{J-H}) methods on weekly basis inside plastic houses.

Month	Period	ET_H	ET_{B-C}	ET_{J-H}
Nov	22-30	1.19	1.79	1.34
Dec	1-7	1.24	1.81	1.39
	8-14	1.03	1.45	1.16
	15-21	1.12	1.68	1.26
	22-31	1.01	1.50	1.13
Jan	1-7	0.78	1.12	0.86
	8-14	1.08	1.42	1.18
	15-21	0.75	0.97	0.82
	22-31	1.00	1.18	1.09
Feb	1-7	1.29	1.60	1.42
	8-14	1.34	1.63	1.48
	15-21	1.25	1.42	1.39
	22-29	1.53	1.74	1.72
Mar	1-7	1.44	1.86	1.60
	8-14	1.98	2.44	2.22
	15-21	2.00	2.49	2.28
	22-31	1.99	2.44	2.27
April	1-7	2.37	3.18	2.77
	8-14	2.18	2.76	2.51
	15-21	2.15	2.87	2.51
	22-30	2.66	2.95	3.06
May	1-7	2.85	3.43	3.27
	8-14	3.07	3.69	3.57
	15-21	3.22	3.88	3.78
	22-31	3.39	3.93	3.99
Total (mm)		**337.40**	**423.18**	**385.05**



Figure(32) Average daily evapotranspiration (ET_m) measured by depletion method and estimated evapotranspiration for grass on weekly basis using Hargreaves (ETH), FAO Blaney-Criddle (ETB-C) and Jensen-Haise (ETJ-H) inside the plastic houses.



Figure(33) Average daily evapotranspiration (ET_m) measured by depletion method and estimated evapotranspiration for alfalfa on weekly basis using Hargreaves (ETH), FAO Blaney-Criddle (ETB-C) and Jensen-Haise (ETJ-H) inside the plastic houses.

was still had the lowest standard errors (SE= 0.19 mm day^{-1}) and the higher determination coefficients (R^2 = 0.93) of estimate over all empirical methods inside the plastic houses.

4-11. Potential evapotranspiration using class-A pan (ETpan)

4-11-1. Class-A Pan evaporation.

Daily class-A pan readings (Epan) for the four pans which located at Deir-Alla Station inside the plastic houses and one in open field nearby the houses were presented in Appendix 1,Table 10. The average daily Epan readings in open field on a weekly monthly basis are presented in Appendix 1,Tables 11 and 12, respectively. The average daily Epan readings inside plastic houses on a weekly and monthly basis are presented in Appendix 1,Tables 12 and 14, respectively. Figure (34) shows Epan values on weekly basis during the growing season . Pan evaporation rate in open field (Ep_O) is much higher than in plastic houses, for all crops. This is mainly due to the wind speed in the open field which is high compared to its value inside plastic houses, and the higher air relative humidity which is also decreased evaporation inside the plastic houses. Evaporation rate inside grass (Ep_G) and alfalfa (Ep_A) plastic houses are higher than that inside tomato (Ep_T) and cucumber (Ep_C) houses (Fig. 34), because plant height of tomato and cucumber are higher than that of

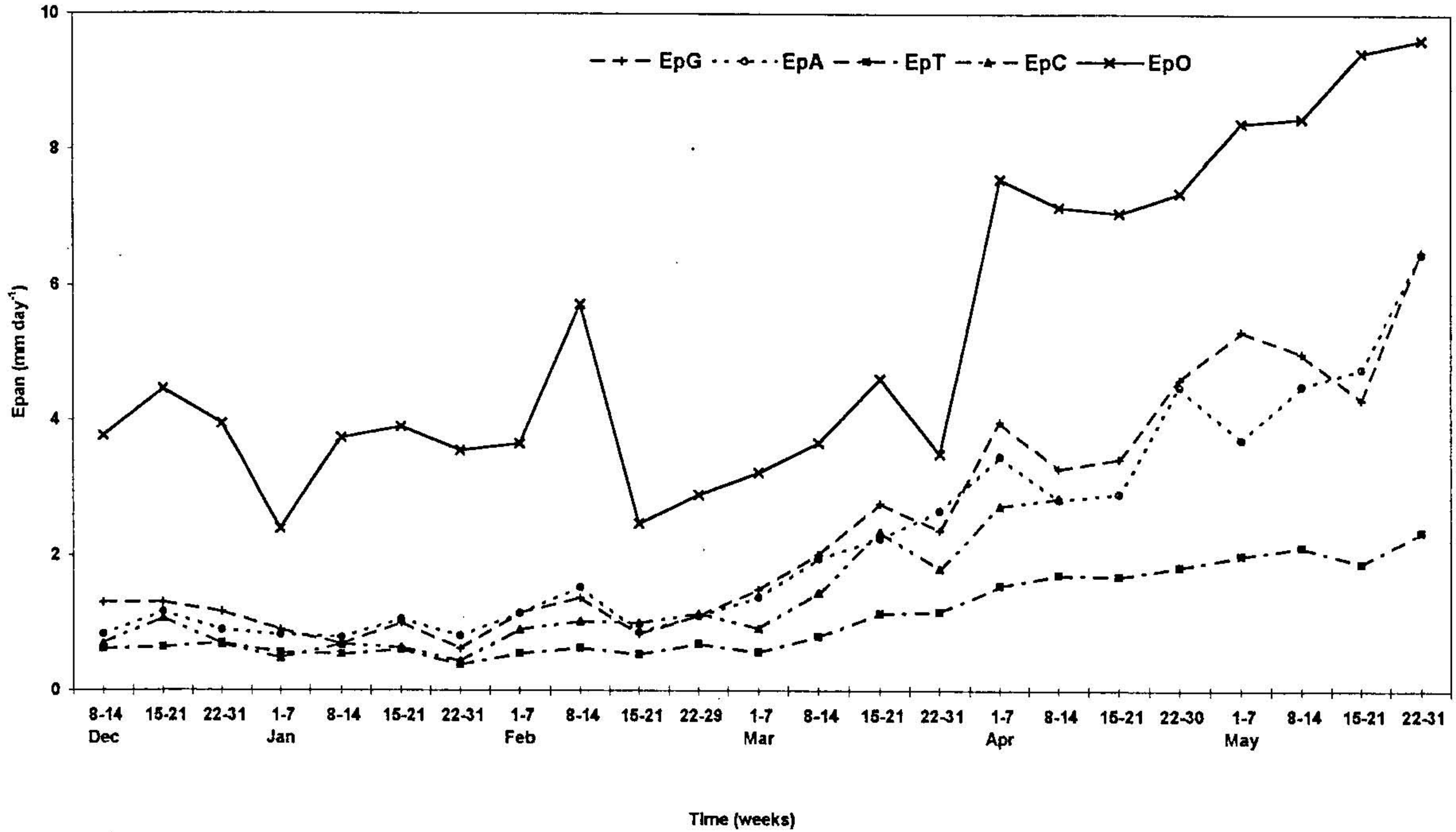


Figure 34. Average daily pan evaporation in open field (Ep_O) and inside plastic houses planted with grass (Ep_G), alfalfa (Ep_A), tomato (Ep_T) and cucumber (Ep_C) on weekly basis .

grass and alfalfa, which causes shading to the pans and reduces the evaporation especially after the plant reach its maximum height at the end of the growing season. Figure (35) shows linear relationships between the average weekly class-A pan evaporation in open field (Ep_O), and evaporation inside plastic houses planted with grass (Ep_G), alfalfa (Ep_A), tomato (Ep_T) and cucumber (Ep_C). The slopes of these regressions are 0.504, 0.4659, 0.2163 and 0.3068 with the corresponding r^2 of 0.78, 0.76, 0.84 and 0.53 for grass, alfalfa, tomato and cucumber plastic houses, respectively (Fig. 35). The evaporation inside grass, alfalfa, cucumber and tomato plastic houses were about 0.50, 0.47, 0.31 and 0.22, respectively, of the evaporation in open field. The reason for these variations is the plant height which causes shading to the pans and reduces the evaporation, especially inside cucumber and tomato plastic houses.

4-11-2. Determination of ETpan in open field.

The potential evapotranspiration using Class-A pan method ETpan in open field are presented in Appendix 1,Tables 13 and 14, on weekly and monthly basis. Significant linear relationships were obtained from correlated weekly ET_o and ET_r estimated using Penman-Monteith equation with ETpan in open field (Figure 36). The relationships show that ET_o values are closer than that of ET_r to measured ETpan in open field because the pan was surrounded by grass crop.

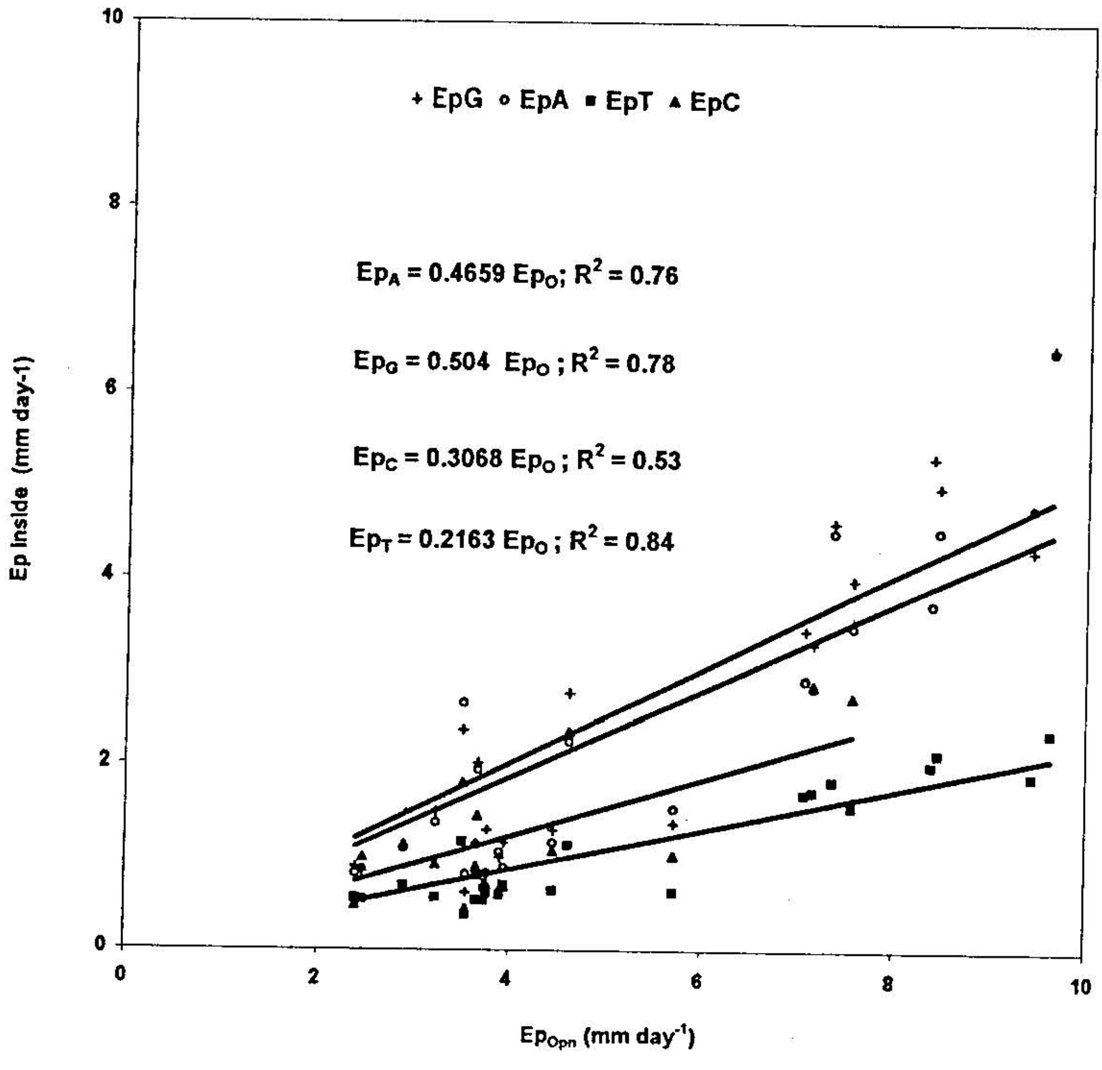


Figure 35 .Comparison between Class-A pan evaporation in open field (Ep_O) and inside plastic houses planted with grass (Ep_G), alfalfa (Ep_A), tomato (Ep_T) and cucumber (Ep_C) on weekly basis during the 1999/2000 growing season.

الصفحة غير موجودة من أصل المصدر

4-11-3. Determination of class-A pan coefficient (Kp) under plastic house condition

Pan coefficients for class-A pan inside grass, alfalfa, tomatoes and cucumbers plastic houses were presented in Appedix1,Tables 15 and 16, on a weekly and monthly basis, respectively. Figures 37, 38 and 39 show the linear relationships between Kp and temperature (Tmax), vapour pressure deficit (VPD), and solar radiation (Rs), respectively on weekly basis in these plastic houses.

Comparing the Kp values inside the plastic houses to that in open field, indicating that;

1- All Kp values for class- A pans under plastic house conditions show higher values (Appendix 1,Table 12), while for open field it was in the range from 0.6 to 0.8. (Appendix 1Table 11). The reason for that variation is the low evaporation rate inside plastic houses due to very low wind speed and high relative humidity in contrast with open field.

2- The linear regression equations between Kp and environmental factors (Tmax, VPD and Rs) inside the plastic houses have negative slopes (Figures 37, 38 and 39). This means that the Kp values decreases with increasing temperature (Tmax), solar radiation (Rs) and vapour pressure deficit (VPD) inside plastic houses.

Linear regressions were made between Kp values and the measured climatic factors inside plastic houses on weekly basis. The Kp of grass

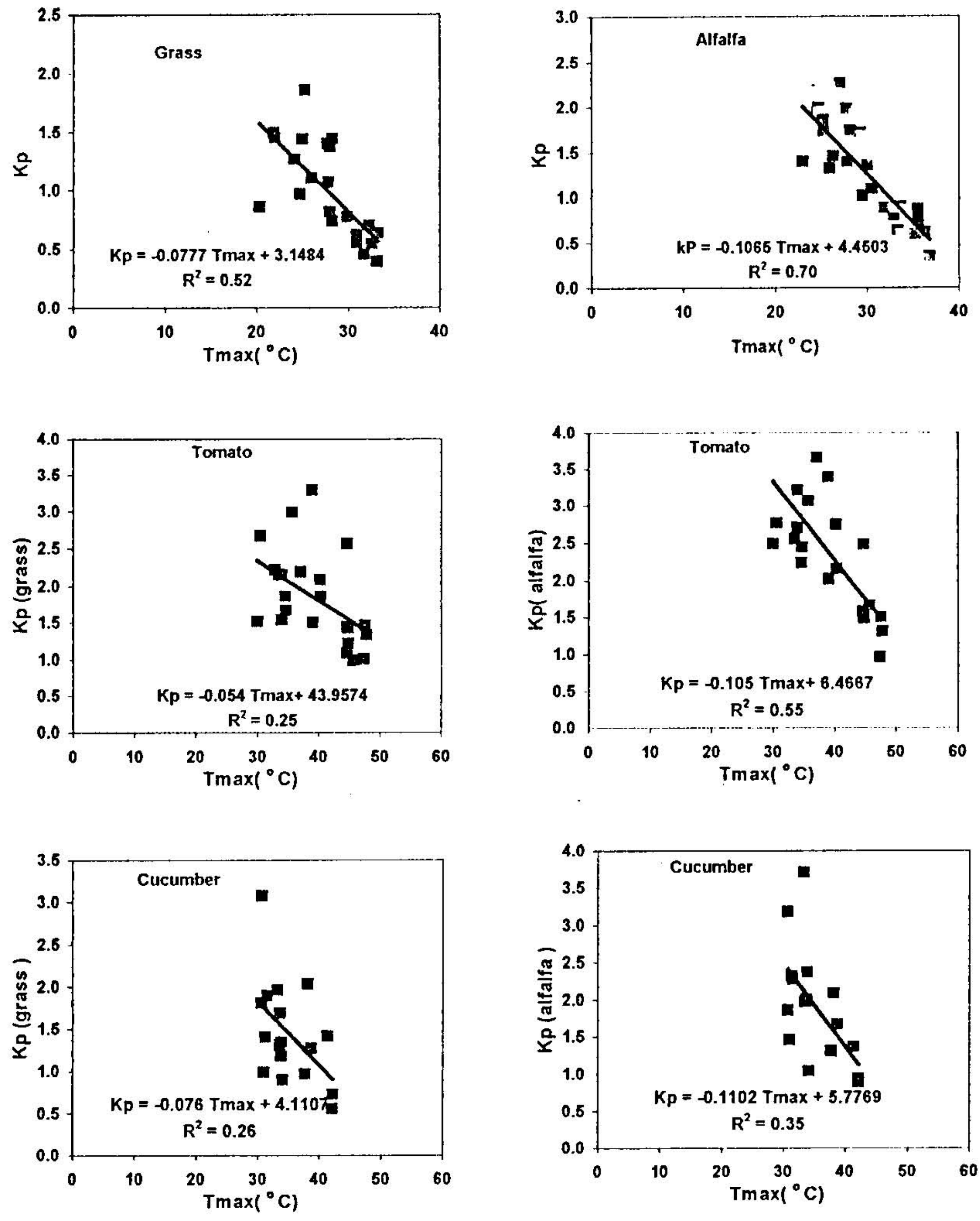


Figure 37. Relationships of class-A pan coefficient (Kp) for the crops studied and maximum temperature (Tmax) on weekly basis under plastic house coditions.

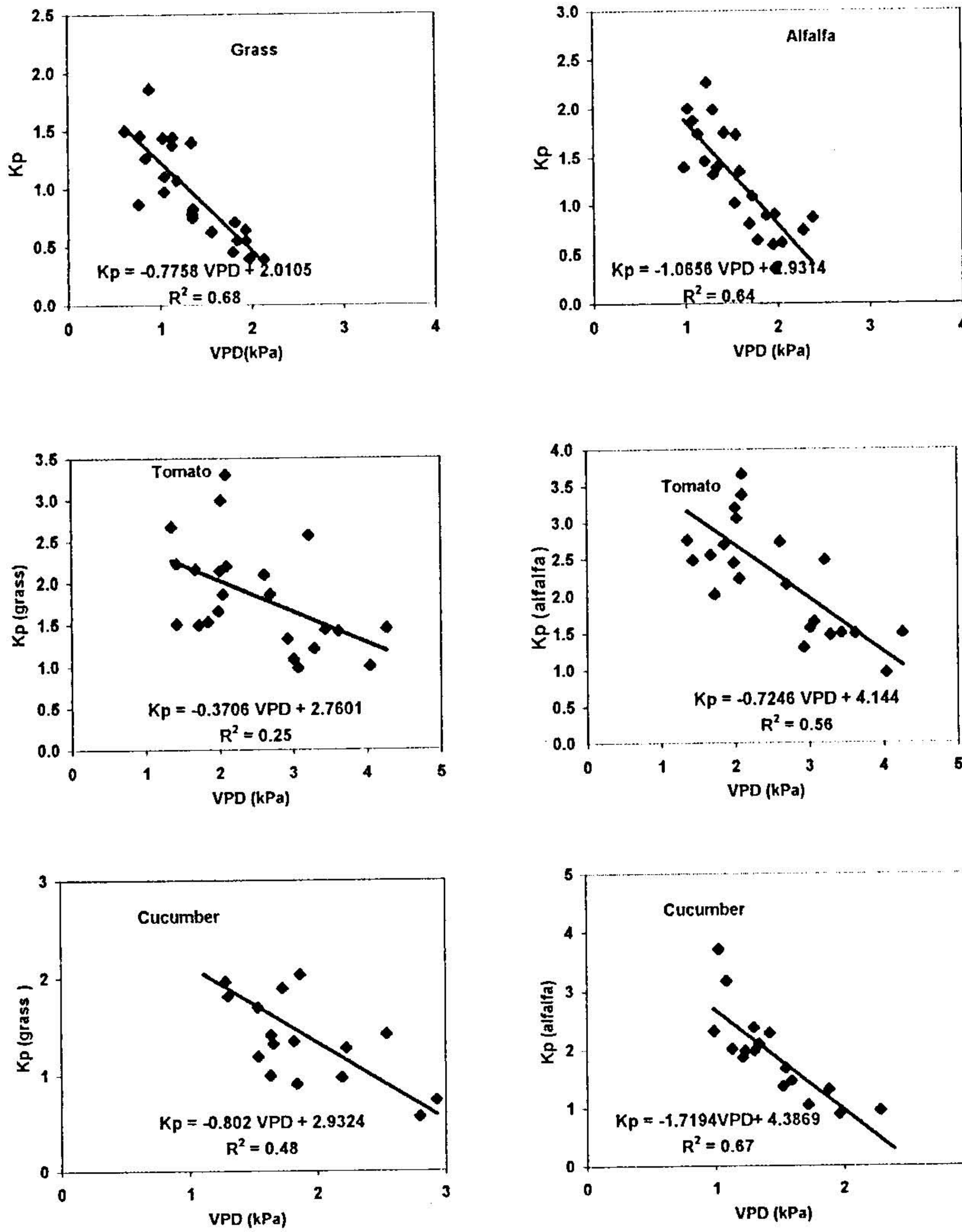


Figure 38. Relationships of class-A pan coefficient (Kp) for the crops studied and vapor pressure diffect (VPD) on weekly basis under plastic house coditions.

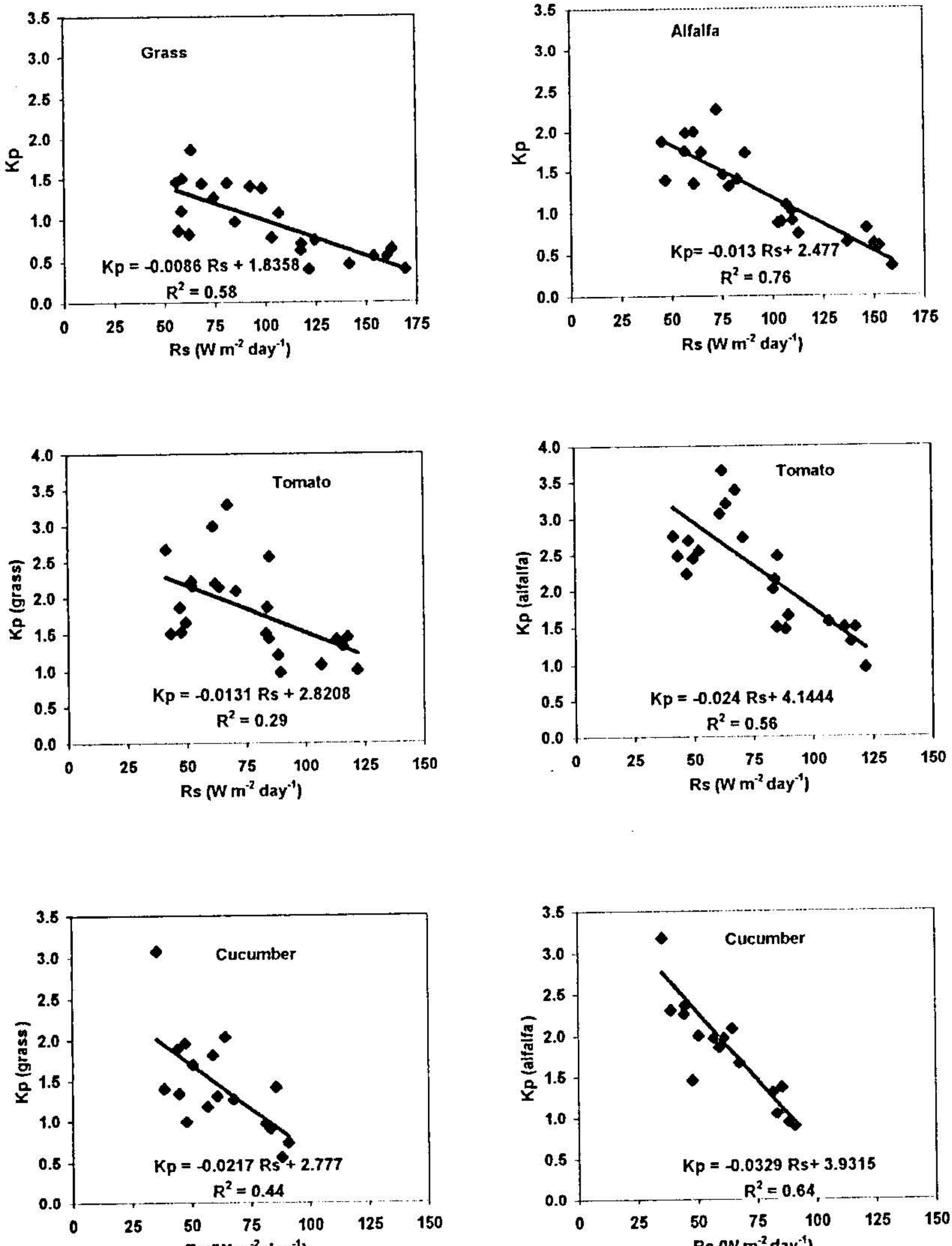


Figure 39 . Relationships of class-A pan coefficients (Kp) for the crops studied and solar radiation (Rs) on weekly basis under plastic house coditions.

3- and alfalfa plastic houses are higher correlated to Tmax, VPD, and Rs than tomato and cucumber (Figures 37, 38 and 39). The lower R^2 (0.25) values for tomato and cucumber are as the result of the plant shading of the pans.

The importance of Kp estimation using climatic factors is to simplify the method for ET estimation using pan readings.

4-12. Effect of environmental factors on ET inside the plastic houses.

Regression equations of ET as a function of each T_{max}, VPD, Rs and Rn on weekly basis are shown in Figures 40, 41, 42 and 43, respectively. T_{max} significantly affected all crops ET values inside plastic houses. Figure 40 shows that actual evapotranspiration (Eta) of tomatoes and grass were highly correlated to T_{max} with correlation coefficients (R^2) of 0.79 and 0.80, respectively. The Eta of tomatoes crop was highly affected by increasing temperature because it has the highest slope of 0.1733 of the linear relation between Eta and T_{max}. Thus increasing temperature 1°C above the threshold value of 28.6 °C increased the Eta of tomato 0.1733 mm day^{-1}. While the threshold values for cucumber, alfalfa and grass are 17.2, 9.8 and 14.5 °C, respectively. So increasing temperature 1 °C above the threshold values increased Eta by 0.0789, 0.1025 and 0.1229 mm day^{-1} for cucumber, alfalfa and grass, respectively.

Linear relationships were obtained between Eta of the crops and the corresponding vapour pressure deficit (VPD) on weekly basis (Fig. 41). All

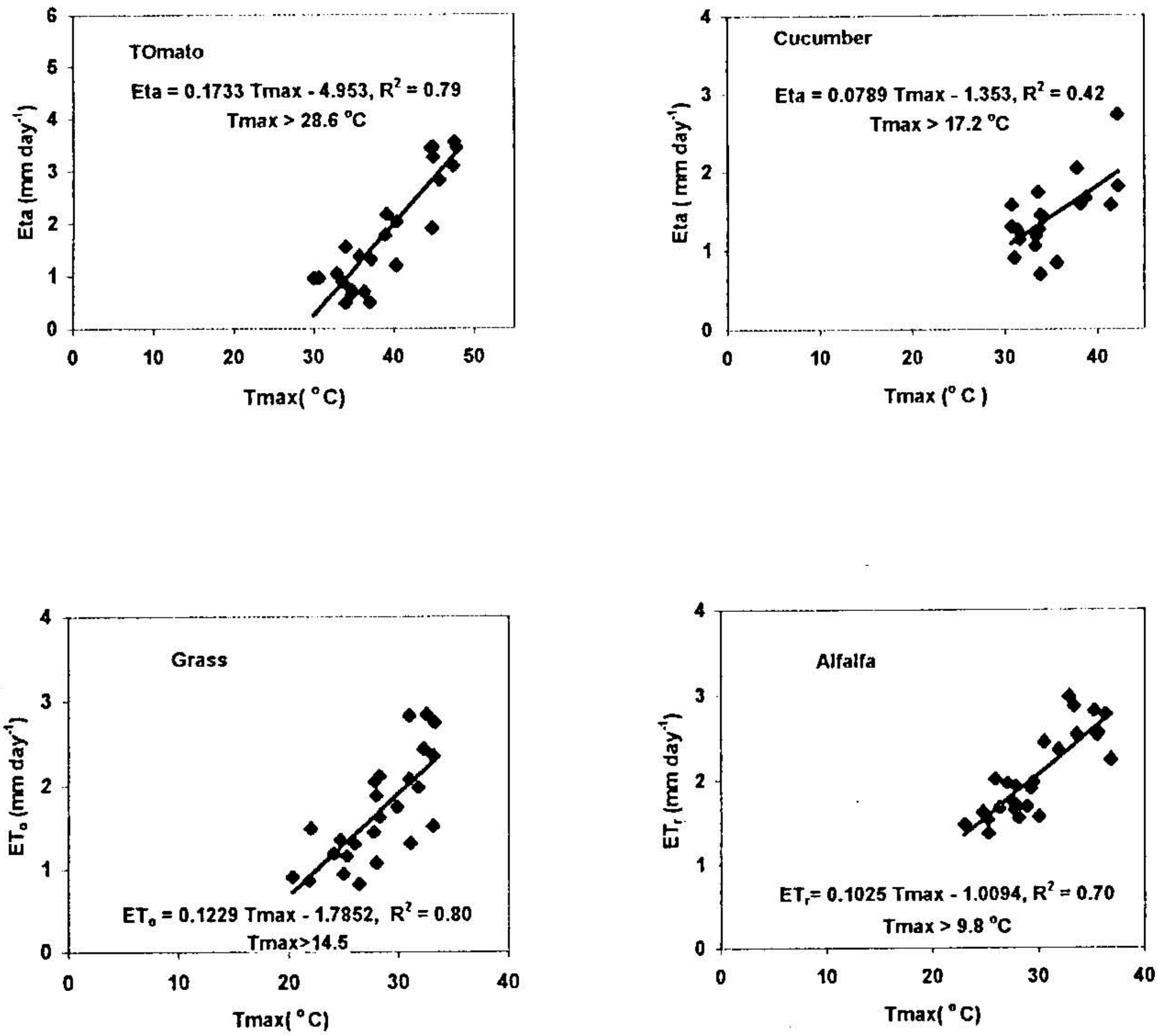


Figure 40 . Relationships of average daily actual evapotranspiration (ET) for the crops studied measured by depletion method and maximum temeprature (Tmax) on weekly basis under plastic house coditions.

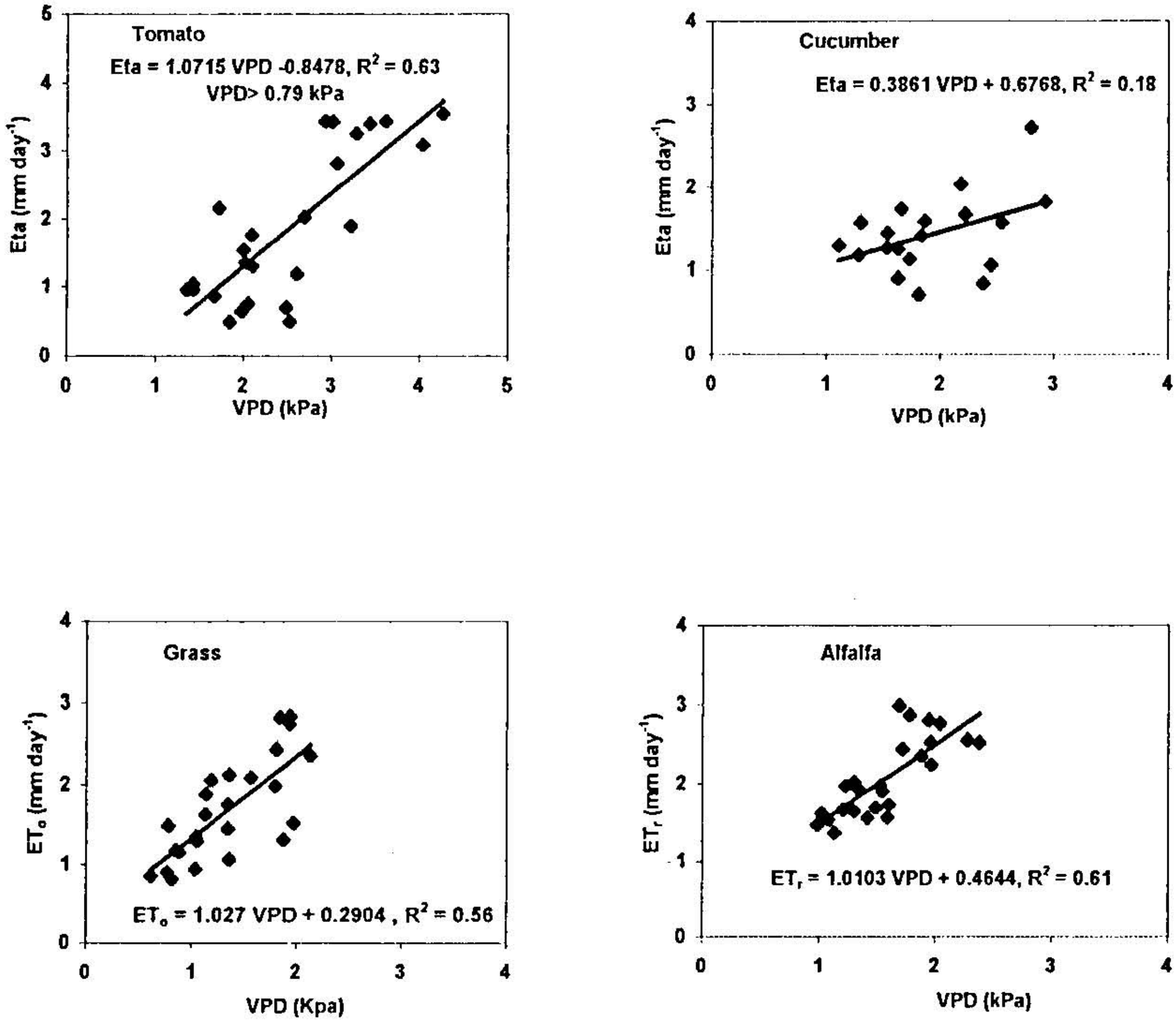


Figure 41 . Relationships of average daily actual evapotranspiration (ET) for the crops studied measured by depletion method and vapor pressure deficet (VPD) on weekly basis under plastic house coditions.

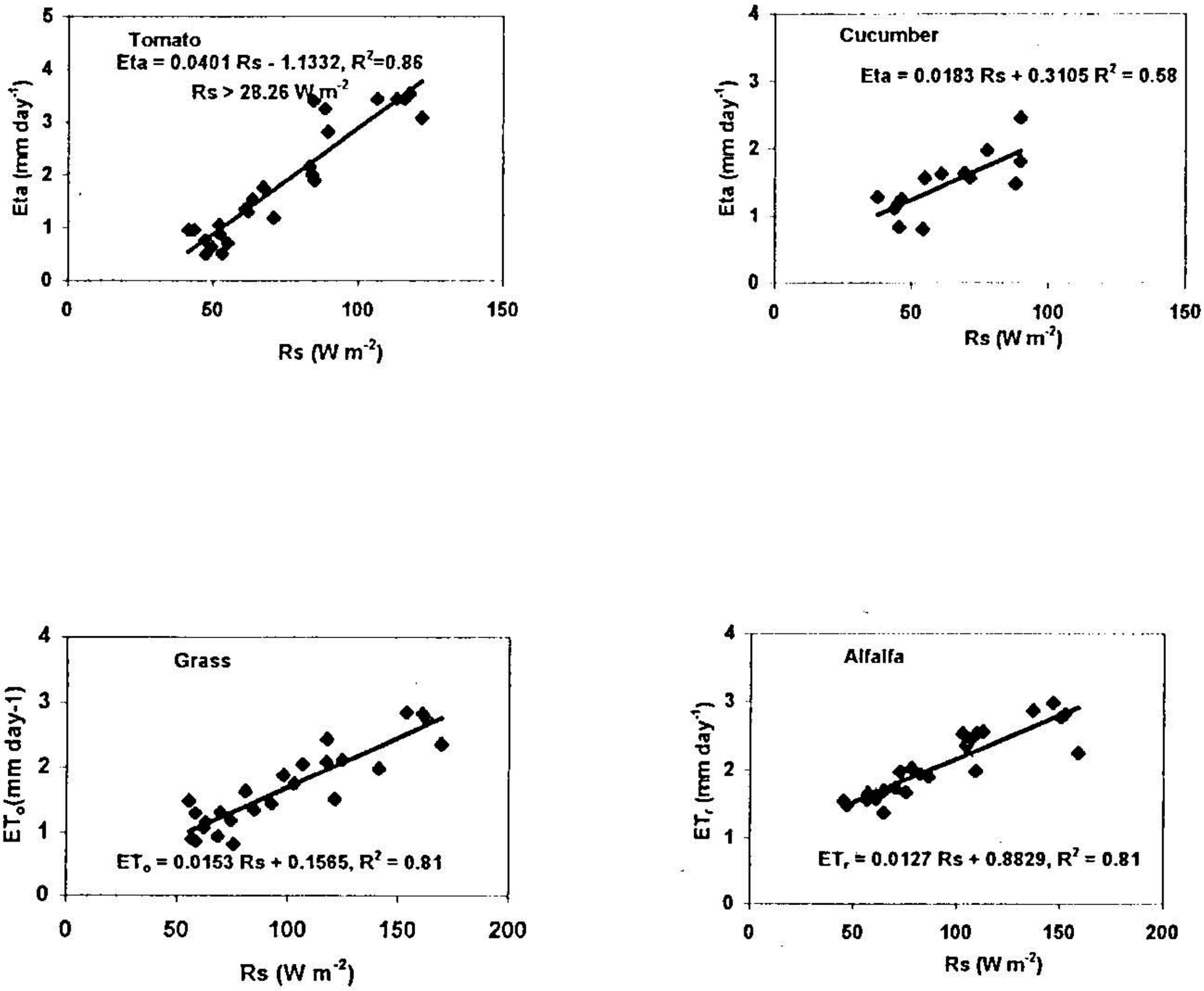


Figure 42 . Relationships of average daily actual evapotranspiration (ET) for the crops studied measured by depletion method and Solar radiation (Rs) on weekly basis under plastic house coditions.

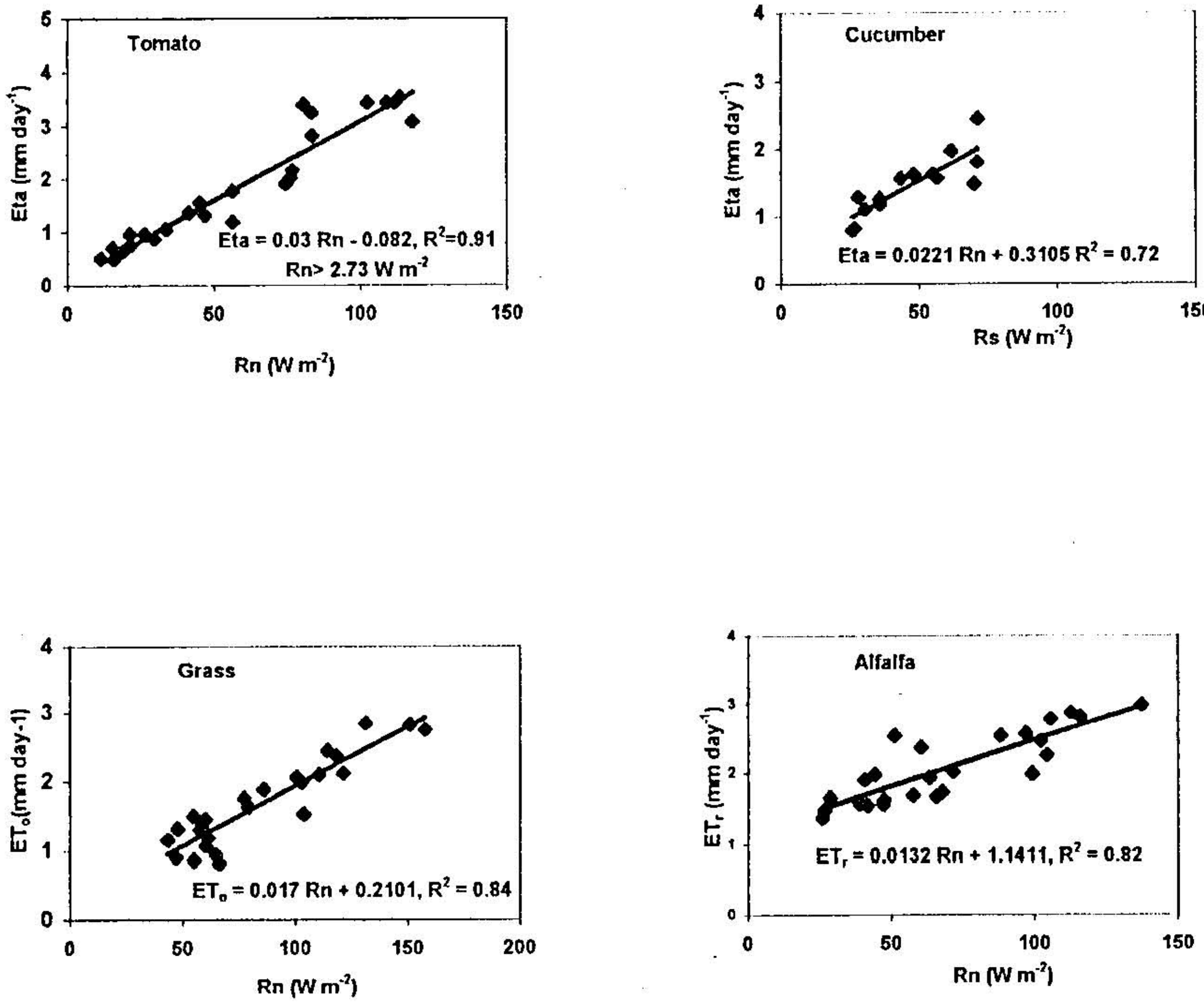


Figure 43 . Relationships of average daily actual evapotranspiration (ET) for the crops studied measured by depletion method and net Solar radiation (Rn) on weekly basis under plastic house coditions.

crops Eta were affected by VPD in similar trend, except cucumber which has low R^2 value of 0.18. The Eta of tomatoes crop has the highest slope and R^2 of 1.0715 and 0.79, respectively, of the linear relation between Eta and VPD. Thus increasing VPD 1 kPa above the threshold value of 0.79 kPa increased the Eta of tomato by 1.0715 mm day^{-1}. While increasing VPD 1 kPa increased Eta by 0.3861, 1.027 and 1.0103 mm day^{-1} for cucumber, alfalfa and grass, respectively.

Figure (42) shows regression equations of Eta as a function of solar radiation for crops inside the plastic houses on weekly basis. All Eta values of the crops were significantly correlated to Rs with r^2 values of 0.81, 0.86, 0.81 and 0.58 for grass, tomato, alfalfa and cucumber, respectively. The highest slope of the linear regressions was for tomato with 0.0401 value which means also that tomato is affected by the Rs higher than the other crops under the study. So increase Rs by 1 W m^{-2} day^{-1} increased the Eta of tomato by 0.0401 mm day^{-1}. While the increase in Rs by 1$Wm^{-2}day^{-1}$ increased Eta by 0.0183, 0.0127 and 0.0153 mm day^{-1} for cucumber, alfalfa and grass, respectively.

Figure (43) shows regression equations of Eta as a function of net solar radiation for crops inside the plastic houses on weekly basis. All Eta values of the crops were significantly correlated to Rs with R^2 values of 0.84, 0.91, 0.81 and 0.72 for grass, tomato, alfalfa and cucumber, respectively. The highest slope of the linear regressions was for tomato with 0.03 value which means also that tomato is affected by the Rn higher than the other crops under the study. So increase Rn by 1 W m^{-2} day^{-1} increased the Eta of tomato by 0.03 mm day^{-1}. While the increase in Rn by 1 $Wm^{-2}day^{-1}$ increased Eta by 0.0221, 0.0132 and 0.017 mm day^{-1} for cucumber, alfalfa and grass, respectively.

From the previous results T_{max}, Rs and VPD can be used in prediction of Eta for the crops inside the plastic houses, and Rn was found to be the best single climatic factor in predicting ET inside the plastic houses.

4-13. Measured evapotranspiration of grass (ET_o), alfalfa (ET_r), cucumber (Eta_C) and tomato(Eta_T) versus evaporation from class-A evaporation (Epan) inside the plastic houses.

Regression equations of ET_o, ET_r, Eta_C and Eta_T as a function of Epan inside the plastic houses on weekly basis were developed (Figure 44). The regression equations were as follows:

ET_o = 0.313 Epan + 0.9498, R^2 = 0.72

ET_r = 0.3582 Epan +1.328, R^2 = 0.88

Eta_C = 0.4262 Epan + 0.9549, R^2 = 0.50

Eta_T = 1.5823 Epan + 0.2233, R^2 = 0.86

The correlation coefficients (R^2) Show significant relationships between the measured ET values for the studied crops and evaporation from class-A pans inside the plastic houses. Thus class-A pan can be used

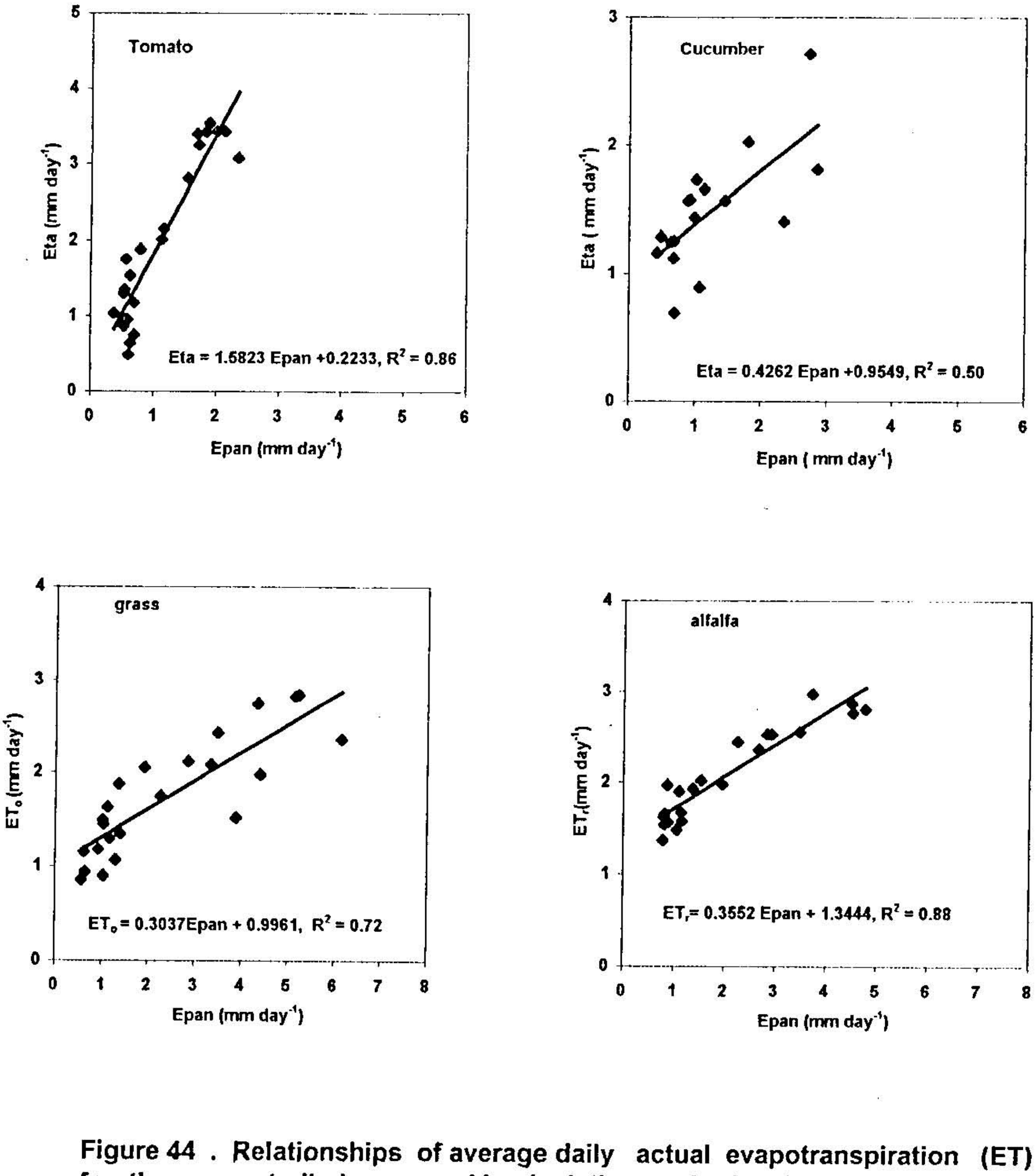


Figure 44 . Relationships of average daily actual evapotranspiration (ET) for the crops studied measured by depletion method and evaporation from Class-A pans on weekly basis under plastic house coditions.

for predicting ET values inside the plastic houses for tomato, alfalfa and grass using the pervious relationships, while pans can be used inside cucumber plastic house with some restrictions due to the low R^2 value.

4-14. Relationships of actual evapotranspiration (Eta) and plant height (hc) for tomato and cucumber crops inside the plastic houses.

The relationships between Eta values and the plant heights for tomato and cucumber crops were presented in Figures (45)and (46), respectively. The Eta values for the two crops were significantly correlated with the plant heights. The exponential regression equations show that the Eta values increased with increasing plant height during the growing season. The increasing rate of Eta values after reaching 200 cm plant height were higher than that of its values before this height for tomato and cucumber crops. The reasons for these high Eta values were; (1) The crops reached its highest productivity after this height, and the plant growth increased in the up-down direction; (2) Climatic factors like high Rs and temperature increased the Eta values, especially at end of the growing season (April and May). The exponential relationships show that at zero plant height the Eta values were 0.3658 and 0.7216 mm day^{-1} for tomato (Fig. 45) and cucumber (Fig. 46), respectively. These Eta values can represented the evaporation inside the plastic houses before transplanting of tomato and cucumber crops.

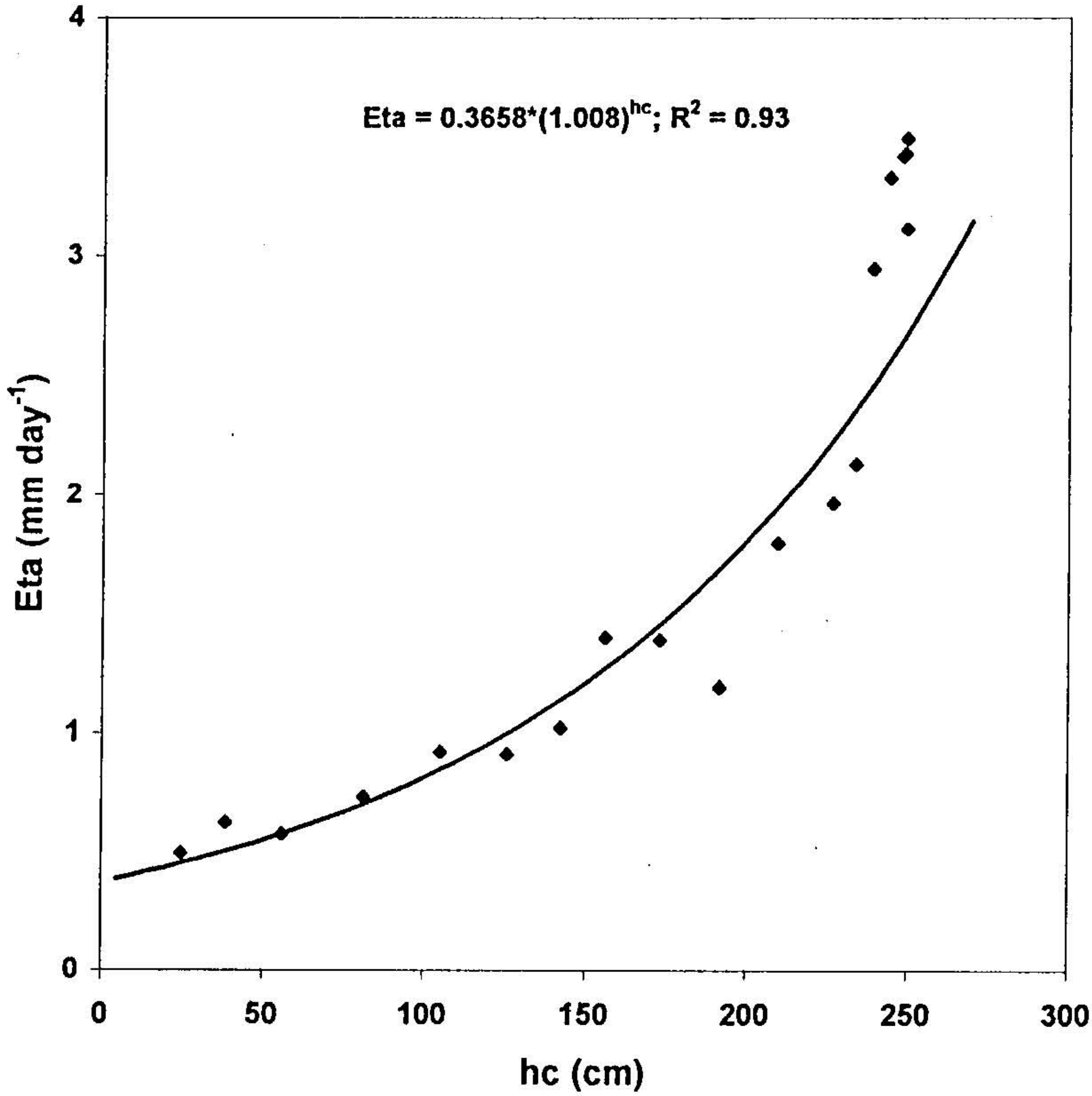


Figure 45. Relationships of actual evapotranspiration (Eta) and plant height (hc) for tomato crops on weekly basis under plastic house conditions.

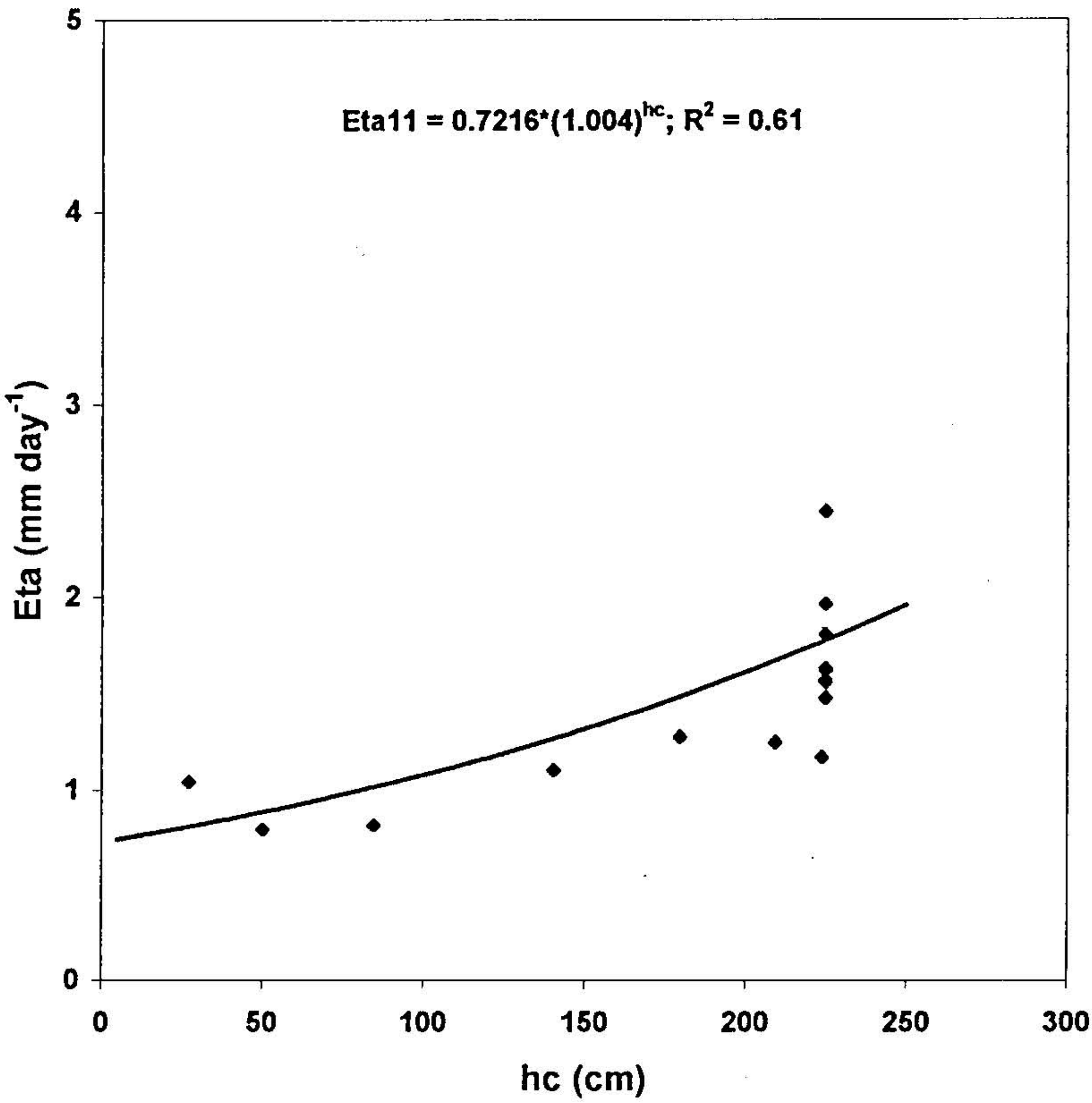


Figure 46. Relationships of actual evapotranspiration (Eta) and plant height (hc) for cucumber crops on weekly basis under plastic house conditions.

5. SUMMARY AND CONCLUSIONS

A study was carried during 1999/2000 growing season, at the National Center for Agricultural Research and Technology Transfer (NCARTT) Station located in Deir-Alla in the Central Jordan Valley, to determine crop coefficients of tomatoes and cucumbers, and to develop models for estimation of evapotranspiration of grass, alfalfa, tomato and cucumber under plastic house conditions.

Two plastic houses were planted with grass and alfalfa as reference crops and they reached their full cover before the starting of the experiment. The other two plastic houses were planted with tomatoes and cucumbers on November 16, 1999. Twelve fiber glass access tubes were installed in each plastic houses distributed along the house to measure soil moisture using TRIME. Daily evaporation readings were recorded from class-A pans which was installed at the center of plastic houses and from a Class-A pan placed in a nearby open field. Average daily temperature and relative humidity values were measured using Thermo-hydrographs located in the center of each plastic house. Actual evapotranpiration of grass, alfalfa, tomatoes and cucumbers were measured by depletion method. Potential ET for grass (ET_o) and alfalfa (ET_r) in open field were estimated by Penman-Monteith and pan method (ETpan). The corresponding crop coefficients (Kc) of tomatoes and cucumbers in plastic houses were estimated also. The plant parameters for all crops under the study measured were: plant height; leaf area index (LAI) using SunScan; total yield; and water use efficiency.

Total amounts of irrigation water added were 428, 500, 429, and 275 mm for grass, alfalfa, tomatoes and cucumbers, respectively. The results showed the following:

1- Total actual evapotranspiration measured by depletion method were 327, 403, 356 and 214 mm for grass, alfalfa, tomatoes and cucumbers, respectively.

2- Growth stage Kc values for tomatoes based on ET_0 inside plastic house ranged from 0.50 to 1.34, and based on ET_r ranged from 0.31 to 0.91.

3- Growth stage Kc values for cucumbers ranged from 0.67 to 1.29 based on ET_0, and ranged from 0.46 to 0.81 based on ET_r inside plastic house.

4- The most important factors affecting ET values in all plastic houses are plant height (hc), solar radiation (Rs), net solar radiation (Rn), vapour pressure deficit (VPD) and maximum air temperature (Tmax).

5- Simplified models were developed to estimate evapotranspiration inside plastic house for grass, alfalfa, cucumbers and tomatoes crops using net radiation (Rn) and VPD, based on the formalism of Penman-Monteith equation: ET= A Rn +B VPD. From a practical point of view, such a model could be a easily implemented algorithm for irrigation.

6- It was possible to derive estimates of leaf aerodynamic resistance (r_a), as well as orders of magnitude of leaf stomatal resistance (r_s) for the four crops under the study. The estimated seasonal aerodynamic resistance (r_a) values were 428, 99, 555, and 1059 s m^{-1}, and the estimated leaf stomatal resistance (r_s) were 924, 448, 393 and 15 s m^{-1} for the plastic houses planted with grass, alfalfa, cucumber and tomatoes crops, respectively.

7- The calculated ET values by Penman-Monteith equation using the estimated r_a and r_s values for the crops studied inside the plastic houses were highly closed to measured ET values when compared to the empirical methods..

8- The measured seasonal potential evapotranspiration (ET) inside the plastic houses was a bout 40% of ET using Penman-Monteith equation in the open field.

9- The ratios of Epan inside tomatoes, cucumbers, alfalfa and grass plastic houses to the open field value were 0.22, 0.31, 0.47 and 0.50, respectively.

10- Weekly and monthly class-A pan coefficients (Kp) for the plastic houses were derived for all pans under the study.

11- Significant relationships between Eta values and plant heights (hc) for tomato and cucumber crops on weekly basis, were derived inside the plastic houses using the following equations:

$Eta = 0.3658*(1.008)^{hc}$; $R^2 = 0.93$ (for tomato)

$Eta = 0.7216*(1.004)^{hc}$; $R^2 = 0.61$ (for cucumber)

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7- APPENDICES

1-APPENDIX 1 : Tables related to results

Table 1. Average daily minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), wind velocity (U, Km day^{-1}), atmospheric pressure (P, kPa), incident solar radiation (Rs, W m^{-2} day^{-1}) and actual sunshine hours (n) were collected from the meteorological Station of Dier-Alla.

Date	Tmin °C	Tmax °C	Rhmin %	RHmax %	U Km day^{-1}	P kPa	Rs W m^{-2} day^{-1}	n hr
01/11/99	18.4	28	26	62	162.6			
02/11/99	18.2	30.5	14	32	280.7			
03/11/99	22.2	32	13	15	312.5			
04/11/99	22.8	31.5	14	19	150.2			
05/11/99	19.2	28.5	20	49	97.9			
06/11/99	20.8	29	37	58	158			
07/11/99	19.6	28	37	51	93.5			
08/11/99	18	28	36	67	159.9			
09/11/99	19	30.6	28	45	110.1			
10/11/99	19	27.5	35	49	125.8			
11/11/99	18.6	27.5	36	51	124.3			
12/11/99	19	27.7	35	56	109.4			
13/11/99	16.2	27.2	27	55	149.6			
14/11/99	17.6	29.7	26	46	99.8			
15/11/99	16.3	28.2	26	56	126.3			
16/11/99	19.2	29	29	46	163.3			
17/11/99	17	30.2	26	34	199			
18/11/99	22	31.2	21	33	210.2			
19/11/99	20.5	29.5	31	33	141.7			
20/11/99	20	29.2	29	48	94.9			
21/11/99	16	30	26	46	77.2			
22/11/99	19	31.8	24	43	82.9	1043.13	126.51	7.6
23/11/99	19.2	31.8	26	48	93.6	1044.33	131.04	8.3
24/11/99	18	27.8	29	55	105.3	1045.53	105.47	5
25/11/99	17	26.2	29	70	133.4	1048.05	69.01	0.2
26/11/99	15.4	22.6	37	51	87.3	1052.85	98.97	4.3
27/11/99	14.4	22.6	29	70	162	1045.54	131.61	8.8
28/11/99	10	20	19	48	140.5	1045.85	136.74	9.6
29/11/99					273.1	1047.33	132.70	9.2
30/11/99					411.91	1043.13	132.02	9.2

Table 1, cont'd

Date	Tmin °C	Tmax °C	Rhmin %	RHmax %	U Km day^{-1}	P kPa	Rs W $m^{-2} day^{-1}$	n hr
01/12/99	9.5	21	18.00	32.00	17.99	1051.55	141.38	9.2
02/12/99	10.5	21	16.00	20.00	182.3	1049.70	137.92	8.9
03/12/99	12	23.6	19.00	29.00	84.9	1047.90	148.62	9.9
04/12/99	13.2	24.5	27.00	36.00	343.9	1046.40	131.99	8.4
05/12/99	16.5	25.4	32.00	70.00	363.3	1044.35	129.63	8.2
06/12/99	18	23	65.00	80.00	173.7	1046.08	76.94	3.4
07/12/99	13.8	32.2	46.00	90.00	200.1	1046.03	129.04	8.2
08/12/99	15.5	23.4	34.00	45.00	282.6	1045.40	77.68	3.5
09/12/99	14.5	24.6	39.00	52.00	138.8	1047.05	142.83	9.5
10/12/99	14	23	43.00	58.00	129.4	1048.70	143.53	9.6
11/12/99	14	23	48.00	63.00	177.7	1046.43	122.67	7.7
12/12/99	18	24.6	48.00	58.00	179.5	1044.75	86.77	4.4
13/12/99	10.5	19.7	57.00	94.00	85.5	1045.03	110.28	6.6
14/12/99	13.9	20	72.00	80.00	101.6	1044.68	45.42	0.6
15/12/99	14	22.4	63.00	85.00	151.7	1048.00	90.47	4.8
16/12/99	11.8	22.8	47.00	70.00	207	1048.55	133.11	8.8
17/12/99	15	23	36.00	53.00	269.3	1047.15	133.82	8.9
18/12/99	16.5	24.6	35.00	49.00	242.1	1045.58	129.16	8.5
19/12/99	16.2	25.2	28.00	50.00	128.5	1046.10	129.87	8.6
20/12/99	13.5	25	25.00	52.00	131	1045.75	75.40	3.5
21/12/99	11.4	24.2	29.00	58.00	104.5	1045.40	87.89	4.7
22/12/99	11.8	22.6	31.00	51.00	108.1	1044.58	101.11	6
23/12/99	12.8	22.2	32.00	47.00	85.4	1046.23	67.84	2.8
24/12/99	14.7	22.8	37.00	52.00	95.8	1047.28	131.76	8.8
25/12/99	14.6	19.3	60.00	84.00	109.5	1047.23	44.81	0.6
26/12/99	13.4	21.6	50.00	89.00	134.8	1046.73	83.40	4.2
27/12/99	13.7	21	60.00	66.00	104.9	1046.78	74.02	3.3
28/12/99	11	23	40.00	63.00	129.6	1046.60	130.13	8.5
29/12/99	10.5	23	40.00	62.00	144.9	1045.13	134.72	8.9
30/12/99	13.4	25.8	34.00	62.00	177.4	1043.90	134.04	8.8
31/12/99	14.8	26.4	38.00	67.00	68.4	1043.05	132.19	8.6

Table 1, cont'd

Date	Tmin °C	Tmax °C	Rhmin %	RHmax %	U Km day^{-1}	P kPa	Rs W m^{-2} day^{-1}	n hr
01/01/00	13	26.4	34	60	138.6	1042.28	129.24	8.3
02/01/00	13.8	23.8	41	62	106.7	1037.45	65.45	2.4
03/01/00	14	24	50	93	90.4	1037.18	99.33	5.5
04/01/00	14.6	16.4	90	95	85.4	1037.73	106.10	6.1
05/01/00	12	15.5	64	72	192.8	1043.10	56.06	1.5
06/01/00	9	15.6	75	100	127.2	1046.80	72.59	3
07/01/00	11	17.4	72	84	124.4	1045.15	50.86	1
08/01/00	12.4	20.2	55	74	112.2	1046.48	145.22	9.6
09/01/00	11.4	17.7	63	95	104	1049.03	68.69	2.6
10/01/00	10.2	16.6	81	99	39.6	1049.78	83.15	3.9
11/01/00	9.5	17.8	50	81	133.8	1049.40	136.26	8.7
12/01/00	8.5	17.4	50	82	162.2	1050.18	124.32	7.6
13/01/00	8.8	18.4	52	72	164.8	1047.85	139.96	9
14/01/00	8.2	18	49	62	238.6	1044.18	127.59	8
15/01/00	10.6	17.5	50	65	186.9	1045.65	76.96	3.2
16/01/00	8.3	16.5	40	56	212.5	1045.10	140.54	8.8
17/01/00	9.8	17	34	43	159.4	1035.78	135.60	8.3
18/01/00	9.8	20.7	43	51	384.3	1039.35	76.20	3
19/01/00	12.2	15.8	7	75	130.4	1041.05	42.42	0
20/01/00	13	17.4	44	80	227.4	1043.48	78.27	3.1
21/01/00	11	13.5	64	88	53	1047.70	47.63	0.4
22/01/00	9.4	16.4	76	87	62.4	1048.58	74.57	2.7
23/01/00	10.6	16.6	65	91	72.7	1047.18	62.23	1.6
24/01/00	9	18	58	80	103.3	1045.18	130.34	7.4
25/01/00	10	21.6	55	68	127.3	1045.18	146.31	8.7
26/01/00	12.6	14.6	86	90	52.5	1040.70	147.03	8.7
27/01/00	10.2	13.6	68	87	109.2	1043.43	44.83	0
28/01/00	6.2	11	73	83	79.4	1051.80	57.05	1
29/01/00	6	15.6	56	88	30.9	1054.85	129.01	7
30/01/00	9.5	18	55	66	201.2	1051.30	157.20	9.3
31/01/00	12.6	19.2	32	53	163.2	1050.68	159.21	9.4

Table 1, cont'd

Date	Tmin °C	Tmax °C	Rhmin %	RHmax %	U Km day^{-1}	P kPa	Rs W m^{-2} day^{-1}	n hr
01/02/00	10.2	17.5	58	72	87	1050.15	134.82	7.3
02/02/00	9	19.2	60	89	137.7	1049.40	119.78	6
03/02/00	10.2	20.4	39	41	223.6	1046.78	161.84	9.4
04/02/00	14	21.8	35	45	163.7	1045.20	163.77	9.5
05/02/00	12.6	20	47	55	115.3	1043.95	134.04	7
06/02/00	11.5	18.5	49	73	139.9	1045.53	87.77	3.2
07/02/00	7.5	19	48	74	160	1046.35	161.09	9
08/02/00	9.7	18.6	34	41	226.3	1049.88	165.95	9.3
09/02/00	10	21.2	36	41	175.7	1046.88	173.45	9.8
10/02/00	11	21.4	27	75	309.2	1045.73	112.17	4.9
11/02/00	14.7	23.5	38	40	173	1043.13	173.14	9.6
12/02/00	14.8	22.8	32	65	210.6	1041.20	171.78	9.4
13/02/00	10.8	13.5	78	97	122.8	1045.53	51.01	0
14/02/00	11	19.6	59	90	122.9	1045.95	147.79	7.4
15/02/00	12.4		62	77	17.14	1045.75	160.72	8.3
16/02/00	12.2	18.5	54	92	24.9	1047.15	98.46	3.5
17/02/00	11.4	18	66	92	102.6	1045.10	56.66	0.3
18/02/00	11	20.3	50	73	114.6	1047.30	186.24	10
19/02/00	11	22	37	78	112	1049.93	172.49	8.9
20/02/00	11	18.2	65	89	124.2	1044.08	59.30	0.4
21/02/00	9.8	22.2	48	93	98.7	1044.80	192.20	10
22/02/00	9.5	20.2	47	83	127.5	1043.75	191.36	10.1
23/02/00	12.5	18.8	55	89	115.7	1045.85	61.99	0.5
24/02/00	11	19.3	51	95	92.3	1048.35	154.04	7.2
25/02/00	6.5	20.2	44	85	104.4	1047.90	197.27	10.3
26/02/00	10	20.5	44	76	110.9	1047.60	197.11	10.2
27/02/00	6.5	18.5	74	75	103.4	1050.40	113.57	4.1
28/02/00	10.3	16.5	6	70	174.1	1049.28	148.90	6.6
29/02/00	10	21.6	57	62	114	1045.68	195.52	9.9

Table 1, cont'd

Date	Tmin °C	Tmax °C	Rhmin %	RHmax %	U Km day^{-1}	P kPa	Rs W m^{-2} day^{-1}	n hr
1/3/000	12	16	85	94	114.5	1050.68	89.28	1
2/3/00	7.6	16.4	70	98	79.6	1051.18	116.45	3.2
3/3/00	11	20	55	77	68.4	1045.80	202.14	10.2
4/3/00	9.7	20.5	51	89	70.3	1050.43	171.29	7.6
5/3/00	11	21.4	51	80	90.5	1046.93	196.57	9.6
6/3/00	10.6	21.6	51	88	73.5	1044.00	195.13	9.4
7/3/00	11	17	66	80	89.7	1047.90	80.14	0
8/3/00	8	17	41	71	100.3	1051.60	192.99	9.1
9/3/00	6.4	19	42	82	91.8	1050.10	207.50	10.2
10/3/00	10.2	20.6	21	40	89.4	1049.40	212.05	10.5
11/3/00	11.6	21.6	43	47	74.1	1047.33	188.05	8.5
12/3/00	13.8	23.5	44	49	79.2	1045.65	187.47	8.4
13/3/00	12	23.5	38	72	74.3	1046.63	197.18	9.1
14/3/00	10.8	22.5	40	64	117.3	1045.55	209.17	10
15/3/00	10.8	24	32	52	231.6	1043.38	214.95	10.3
16/3/00	13.2	26.2	32	54	160.8	1036.25	205.92	9.6
17/3/00	15.5	26	32	55	88.8	1039.45	217.03	10.4
18/3/00	12.2	28	31	74	108.4	1043.80	210.31	9.8
19/3/00	11.5	23.2	31	37	99	1044.93	224.09	10.8
20/3/00	11.8	24.6	37	66	141.2	1042.45	198.08	8.7
21/3/00	14.2	19.2	73	91	131.9	1036.68	88.26	0.1
22/3/00	14	21.7	60	91	68.5	1036.28	141.62	4.2
23/3/00	10	22	44	70	159.7	1038.85	181.14	7.2
24/3/00	9.5	19.5	60	94	31.7	1047.60	169.04	6.2
25/3/00	11.2	22.5	45	76	129.7	1045.50	145.07	4.3
26/3/00	12.2	24.6	43	84	91.5	1046.55	224.19	10.3
27/3/00	13	26.6	34	45	178.4	1047.95	232.83	10.9
28/3/00	13	30.2	30	70	119.6	1047.25	224.78	10.2
29/3/00	12.4	25	39	76	112.1	1045.05	154.57	4.8
30/3/00	13.6	26.8	30	80	83.7	1041.63	186.93	7.2
31/03/00	12.2	22.6	30	83	112.1	1037.78	238.16	11

Table 1, cont'd

Date	Tmin °C	Tmax °C	Rhmin %	RHmax %	U Km day-1	P kPa	Rs W m-2 day-1	n hr
01/04/00	15.7	32.4	32	39	199.2	1037.28	188.90	7.2
02/04/00	23	34.6	26	34	63.9	1039.70	213.65	9
03/04/00	16.8	29.6	45	74	169.6	1042.60	217.56	9.2
04/04/00	14	29	45	75	138.1	1041.75	202.24	8
05/04/00	14.4	31	25	81	83.4	804.65	215.29	8.9
06/04/00	18.6	33.2	34	77	116.4	1039.38	163.42	5
07/04/00	20.2	27.6	36	75	137.8	1043.03	234.96	10.2
08/04/00	15.2	26.2	47	73	132.9	1041.23	205.72	8
09/04/00	14	25.5	44	72	217.8	1044.15	206.60	8
10/04/00	12	24.6	42	63	180.9	1042.25	241.90	10.5
11/04/00	13	29	34	77	105	1034.65	189.04	6.6
12/04/00	18	31	38	59	112.9	1034.03	151.23	3.8
13/04/00	19.7	34	46	70	104.4	1035.73	165.66	4.8
14/04/00	14.4	27.8	49	75	129.7	1038.65	236.57	9.9
15/04/00	16.4	29.2	47	74	89.7	1035.33	246.80	10.6
16/04/00	14.5	34.2	20	81	234.5	1032.70	261.33	11.6
17/04/00	16	35	20	81	115.5	1027.98	200.81	7.2
18/04/00	19.3	35.2	31	57	110.1	1029.35	191.63	6.5
19/04/00	21.8	32	34	50	183.5	1035.63	101.51	0
20/04/00	18	30.4	31	75	159.3	1038.28	160.48	4.2
21/04/00	16.2	28	40	72	176	1040.95	146.93	3.2
22/04/00	12.4	28.4	36	64	193.9	1042.15	260.82	11.3
23/04/00	16	29.2	39	75	122.5	1041.48	234.64	9.4
24/04/00	15.8	29.8	31	81	130.6	1041.90	249.19	10.4
25/04/00	15.4	30.4	30	74	149.8	1037.63	264.96	11.5
26/04/00	14.2	33	22	69	14.7.7	1035.18	269.73	11.8
27/04/00	14.4	33	36	74	155.6	1035.70	216.96	8
28/04/00	19.5	33	45	76	132.5	1040.28	252.22	10.5
29/04/00	16.3	29	39	74	143.5	1041.75	262.63	11.2
30/04/00	16.8	29.5	45	74	121.2	1041.05	229.48	8.8

Table 1, cont'd

Date	Tmin °C	Tmax °C	Rhmin %	RHmax %	U Km day^{-1}	P kPa	Rs W m^{-2} day^{-1}	n hr
01/05/00	14.4	31.4	35	71	169.6	1041.95	281.03	12.4
02/05/00	16.5	36	36	72	159.3	1034.55	250.37	10.2
03/05/00	18.2	36.6	20	71	131.2	1032.20	242.64	9.6
04/05/00	25.2	37.6	20	55	169.4	1036.55	260.07	10.8
05/05/00	18.8	30.5	33	62	149.5	1039.50	280.48	12.2
06/05/00	17.2	30.6	34	66	195.4	1042.73	279.62	12.1
07/05/00	15.2	29.2	37	61	126.7	1043.20	272.83	11.6
08/05/00	16.6	27.4	37	56	145.3	1042.90	261.62	10.8
09/05/00	16.4	31.6	33	65	188.6	1040.78	281.84	12.2
10/05/00	17	37	18	46	190.3	1036.95	279.19	12
11/05/00	22	37.6	30	34	132.3	1038.53	276.39	11.8
12/05/00	16.5	34.6	31	65	128.2	1037.08	253.86	10.2
13/05/00	16.2	34.4	27	65	122.9	1038.78	279.62	12
14/05/00	19.8	36.2	36	60	170.5	1038.43	281.33	12.1
15/05/00	18.6	35.5	31	72	123	1038.20	280.23	12
16/05/00	18.5	34.4	34	73	136.1	1038.83	282.07	12.1
17/05/00	19.2	36.4	29	82	135.9	1032.85	278.11	11.8
18/05/00	23.8	36.5	32	55	181.2	1036.05	258.37	10.4
19/05/00	18.8	32.4	38	63	147.2	1037.35	253.16	10
20/05/00	19	33	30	73	138.2	1038.33	296.01	13
21/05/00	18.6	34	29	67	140.8	1040.23	296.04	13
22/05/00	17	34.5	27	52	118.2	1037.20	296.50	13
23/05/00	17.2	32.2	43	75	132.2	1035.28	286.71	12.3
24/05/00	18.2	32.2	43	75	147	1036.53	285.82	12.2
25/05/00	19	36.6	25	67	128.9	1035.55	277.45	11.6
26/05/00	22	33.6	38	74	123.3	1037.21	257.94	10.2
27/05/00	19	33.5	0	80	138.5	1037.19	279.47	11.7
28/05/00	20	34.2	37	74	125.7	1037.02	287.19	12.2
29/05/00	20.5	37.2	36	77	153.5	1036.57	294.51	12.7
30/05/00	21.4	39.5	33	76	145.8	1036.48	311.53	13.9
31/05/00	23.6	39	26	51	149.1	1036.65	311.24	13.9

Table 2. Average daily minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), incident solar radiation (Rs, W M^{-2} day^{-1}) and net radiation (Rn, W M^{-2} day^{-1}) on weekly basis were collected inside grass plastic house.

Date	Period	Tmin °C	Tmax °C	Rhmin %	RHmax %	Rs W M^{-2} day^{-1}	Rn W M^{-2} day^{-1}
Nov							
	22-30	6.22	31.11	19.33	89.11	69.76	47.76
Dec	1-7	6.30	26.40	52.57	100.00	75.73	66.28
	8-14	9.00	25.00	45.00	70.00	68.51	64.84
	15-21	9.50	28.00	35.00	77.00	62.14	60.47
	22-31	10.00	26.00	44.67	80.00	58.39	43.92
Jan	1-7	7.43	22.00	41.29	98.29	55.71	47.63
	8-14	4.14	25.29	45.14	98.29	63.08	59.32
	15-21	5.29	20.36	38.00	93.29	57.11	55.42
	22-31	3.70	21.85	53.40	98.00	58.78	42.94
Feb	1-7	5.14	28.29	42.00	94.71	81.02	70.91
	8-14	5.79	24.71	36.71	86.57	85.01	80.45
	15-21	5.43	24.14	44.00	98.29	74.31	72.32
	22-29	5.25	27.75	28.13	97.75	92.66	61.86
Mar	1-7	5.36	28.00	39.71	99.57	98.31	86.04
	8-14	5.00	27.86	36.57	100.00	106.65	100.94
	15-21	7.71	28.29	30.43	95.71	124.70	121.36
	22-31	7.20	29.90	36.50	97.10	103.16	93.59
Aprl	1-7	13.14	33.14	25.57	88.57	121.31	83.70
	8-14	9.86	31.00	31.29	96.71	117.59	106.40
	15-21	12.00	32.29	27.14	92.71	117.93	112.78
	22-30	11.11	31.78	24.22	97.44	141.47	102.10
May	1-7	12.43	32.57	22.29	96.29	153.71	131.43
	8-14	12.43	31.00	22.57	85.71	160.60	151.02
	15-21	14.07	33.29	26.29	93.86	162.61	157.81
	22-31	15.05	33.20	18.50	93.00	169.52	118.54

Table 3. Average daily minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), incident solar radiation (Rs, W M^{-2} day^{-1}) and net radiation (Rn, W M^{-2} day^{-1}) on weekly basis were collected inside Alfalfaplastic house.

Date	Period	Tmin °C	Tmax °C	Rhmin %	RHmax %	Rs W M^{-2} day^{-1}	Rn W M^{-2} day^{-1}
Nov							
	22-30	12.28	28.89	30.22	84.89	65.03	57.66
Dec	1-7	11.19	27.70	25.86	65.00	70.36	64.33
	8-14	12.62	27.78	36.86	82.71	57.29	53.51
	15-21	10.95	30.08	30.43	83.00	61.26	58.29
	22-31	11.06	28.17	30.40	85.60	56.87	54.62
Jan	1-7	11.43	25.24	37.86	86.86	45.54	43.74
	8-14	9.21	25.32	36.14	82.14	64.84	62.27
	15-21	9.29	23.02	36.14	84.29	46.96	45.10
	22-31	9.00	24.72	38.40	87.70	60.93	39.49
Feb	1-7	9.84	26.35	34.29	85.29	75.67	59.75
	8-14	10.48	25.95	30.00	79.29	78.20	71.62
	15-21	9.92	27.06	35.29	87.57	72.76	69.89
	22-29	9.72	29.31	28.75	84.00	86.61	49.43
Mar	1-7	9.84	27.86	32.57	87.43	82.58	63.21
	8-14	10.79	29.52	30.00	86.71	109.56	99.27
	15-21	12.62	30.56	28.00	79.86	106.75	102.38
	22-31	12.39	31.94	25.90	82.20	104.41	60.62
Aprl	1-7	16.51	35.63	27.43	81.86	112.83	96.93
	8-14	13.89	33.65	29.29	84.71	109.74	103.84
	15-21	16.19	35.56	23.43	82.14	102.89	89.25
	22-30	12.53	33.40	33.67	89.22	136.93	83.31
May	1-7	12.94	32.94	36.00	88.00	146.70	128.62
	8-14	13.57	36.35	36.00	86.29	150.38	103.23
	15-21	17.24	35.29	35.29	89.86	152.74	115.94
	22-31	16.79	36.86	38.00	96.10	158.86	104.40

Table 4. Average daily minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), incident solar radiation (Rs, W M^{-2} day^{-1}) and net radiation (Rn, W M^{-2} day^{-1}) on weekly basis were collected inside tomato plastic house.

Date	Period	Tmin °C	Tmax °C	Rhmin %	RHmax %	Rs W M^{-2} day^{-1}	Rn W M^{-2} day^{-1}
Nov							
	22-30	14.78	37.00	23.11	85.44	53.20	11.58
Dec	1-7	13.36	36.29	25.14	69.57	55.12	15.71
	8-14	14.21	34.00	34.86	85.00	47.74	15.79
	15-21	12.29	34.71	31.86	85.71	49.56	19.24
	22-31	13.95	34.60	28.20	90.20	47.23	21.83
Jan	1-7	12.86	30.57	41.14	90.57	41.53	21.60
	8-14	11.79	33.57	38.29	89.86	52.26	29.75
	15-21	12.14	30.00	35.14	91.86	43.38	26.43
	22-31	9.90	32.90	44.50	93.50	52.02	33.82
Feb	1-7	13.00	35.71	32.00	94.86	61.13	41.58
	8-14	13.71	34.00	30.43	80.14	63.70	45.43
	15-21	13.71	37.14	34.57	95.57	62.07	46.75
	22-29	13.88	40.25	31.38	94.13	70.82	56.44
Mar	1-7	13.71	38.93	40.29	97.43	67.46	56.62
	8-14	14.57	44.71	32.86	94.14	85.08	74.60
	15-21	15.86	40.36	31.14	88.43	83.99	76.09
	22-31	13.06	39.08	51.80	95.80	83.40	76.71
Aprl	1-7	19.40	45.70	39.00	96.71	89.60	83.50
	8-14	16.71	44.86	32.14	93.86	88.40	83.29
	15-21	19.14	44.71	29.57	90.29	84.67	80.61
	22-30	18.11	44.67	36.78	96.67	106.62	102.49
May	1-7	20.29	44.86	26.71	88.86	113.33	109.12
	8-14	21.14	47.86	47.57	98.14	116.00	111.81
	15-21	20.14	47.57	24.14	90.00	117.79	113.65
	22-31	20.70	47.40	27.60	90.30	121.99	117.86

Table 5. Average daily minimum temperature (Tmin, °C), maximum temperature (Tmax, °C), minimum relative humidity (RHmin, %), maximum relative humidity (RHmax, %), incident solar radiation (Rs, W M^{-2} day^{-1}) and net radiation (Rn, W M^{-2} day^{-1}) on weekly basis were collected inside cucumberplastic house.

Date	Period	Tmin °C	Tmax °C	Rhmin %	RHmax %	Rs W M^{-2} day^{-1}	Rn W M^{-2} day^{-1}
Nov							
	22-30	15.29	33.25	16.25	63.50	50.84	18.21
Dec	1-7	11.64	35.57	25.14	69.57	55.01	25.75
	8-14	11.83	33.83	34.86	85.00	44.79	23.85
	15-21	12.50	31.00	31.86	85.71	47.90	29.75
	22-31	10.40	31.60	28.20	90.20	44.46	31.24
Jan	1-7	11.07	30.71	49.57	100.00	35.60	26.31
	8-14	9.43	33.71	43.57	90.14	50.69	38.90
	15-21	10.57	31.29	30.86	90.00	38.89	26.92
	22-31	8.50	33.30	49.70	99.60	47.63	37.75
Feb	1-7	5.64	30.71	41.29	98.29	59.16	46.91
	8-14	8.36	33.57	38.00	91.00	61.14	48.48
	15-21	8.71	33.86	41.57	100.00	56.89	45.11
	22-29	9.25	38.75	35.50	100.00	67.71	53.70
Mar	1-7	9.00	38.14	44.00	100.00	64.56	51.20
	8-14	9.49	41.41	36.00	100.00	85.66	67.93
	15-21	10.00	34.13	35.00	83.71	83.46	66.18
	22-31	8.83	37.78	35.20	87.90	81.63	64.73
April	1-7	13.57	42.13	34.71	86.00	88.21	69.96
	8-16	11.17	42.22	31.11	89.00	91.01	72.17
	15-21	19.14	44.71	29.57	90.29	84.67	80.61

Table 6. Average weekly Plant height (cm) measured inside plastic houses for tomato , cucumber, alfalfa and grass in the Central Jordan Valley during 1999/2000 growing season.

Month	Period	Tomato	Cucumber	Alfalfa	Grass
Nov	22-30	24.70	27.20	36.89	14.00
Dec	1-7	36.46	46.56	41.00	14.00
	8-14	46.89	64.02	44.50	21.00
	15-21	61.94	98.59	48.00	28.00
	22-31	82.71	143.10	50.00	20.40
Jan	1-7	102.05	174.27	50.00	13.00
	8-14	117.02	198.01	50.00	20.00
	15-21	130.83	137.41	50.00	27.00
	22-31	143.34	224.28	29.00	17.50
Feb	1-7	153.71	224.90	28.00	14.00
	8-14	164.97	224.91	42.00	21.00
	15-21	177.86	224.91	50.00	28.00
	22-29	192.64	224.92	27.50	13.75
Mar	1-7	206.89	224.93	26.00	14.00
	8-14	219.77	224.94	40.00	21.00
	15-21	229.78	224.94	49.71	28.00
	22-31	234.22	224.95	21.20	31.40
April	1-7	238.47	224.96	34.00	9.00
	8-14	241.97	224.97	47.14	16.00
	15-21	245.47		44.29	23.00
	22-30	248.42		20.00	1.27
May	1-7	248.97		36.00	13.00
	8-14	249.32		32.32	20.00
	15-21	249.67		26.50	27.00
	22-31	250.10		24.85	13.10

Table 7. Average weekly Plant leaf area index (LAI) measured inside plastic houses for tomato , cucumber, alfalfa and grass in the Central Jordan Valley during 1999/2000 growing season.

Month	Period	Tomato	Cucumber	Alfalfa	Grass
Nov	22-30	0.26	0.28	3.19	2.47
Dec	1-7	0.40	0.47	3.65	2.47
	8-14	0.53	0.65	4.05	3.86
	15-21	0.73	1.01	4.44	5.26
	22-31	1.05	1.46	4.67	3.75
Jan	1-7	1.38	1.78	4.67	2.27
	8-14	1.68	2.02	4.67	3.67
	15-21	1.99	1.40	4.67	5.06
	22-31	2.30	2.29	2.30	3.17
Feb	1-7	2.58	2.29	2.18	2.47
	8-14	2.93	2.29	3.77	3.86
	15-21	3.37	2.29	4.67	5.26
	22-29	3.96	2.29	2.13	2.42
Mar	1-7	4.62	2.29	1.96	2.47
	8-14	4.60	2.29	3.54	3.86
	15-21	4.57	2.29	4.64	5.26
	22-31	4.66	2.29	1.42	5.93
April	1-7	4.75	2.29	2.86	1.48
	8-14	4.82	2.29	4.35	2.87
	15-21	4.88		4.02	4.26
	22-30	4.94		1.28	2.98
May	1-7	4.95		3.09	2.27
	8-14	4.96		2.67	3.67
	15-21	4.97		2.02	5.06
	22-31	4.98		1.83	2.29

Table 8. Relationship of leaf area index (LAI) and crop height (hc) and the corresponding r^2 for grass, alfalfa, tomatoes and cucumbers under plastic house conditions.

Crop	Equation	r^2
Grass	LAI = 0.1858 hc	0.97
Alfalfa	LAI = 0.113 hc – 0.9795	0.99
Tomatoes	LAI = 0.0228 hc –0.5089	0.95
Cucumbers	LAI = 0.0102 hc	0.98

hc = cm

Table 9. Relationship of net solar radiation (Rn) and crop height (hc) and the corresponding r^2 for grass, alfalfa, tomatoes and cucumbers under plastic house conditions.

Crop	Equation	r^2
Grass	Rn = Rs (0.3982ln(hc) – 0.2998)	0.85
Alfalfa	Rn = Rs (0.4808ln(hc) – 0.8879)	0.94
Tomatoes	Rn = Rs (0.3008ln(hc) – 0.1235)	0.96
Cucumbers	Rn = Rs (0.2035 ln(hc) – 0.309)	0.92

hc : crop height (cm)

Rs : solar radiation inside plastic houses (W m^2 day^{-1})

Rn : net solar radiation inside plastic houses (W m^{-2} day^{-1})

Table 10. Average daily evaporations from Class-A pans installed inside plastic houses and in open field at Deir-Alla Station during the 1999/2000 growing season.

Date	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}	$Epan_O$ mm day^{-1}
01/12/99					3.4
02/12/99					4.6
03/12/99					7.8
04/12/99					10
05/12/99					11
06/12/99					7
07/12/99					5.8
08/12/99					5.7
09/12/99					3.8
10/12/99					3.6
11/12/99					5.2
12/12/99					3
13/12/99	1.3	0.9	0.7	0.9	3
14/12/99	1.3	0.8	0.5	0.5	2.1
15/12/99	1.3	0.8	0.5	0.5	3.4
16/12/99	1.3	0.8	0.5	0.5	3.6
17/12/99	1.3	1.2	0.6	1.1	6.4
18/12/99	1.3	1.8	0.9	2.1	7.6
19/12/99	1.3	1.8	0.9	1.5	3
20/12/99	1.3	1.0	0.5	0.7	4
21/12/99	1.3	0.8	0.6	1.1	3.2
22/12/99	1.3	0.8	0.9	0.8	5
23/12/99	1.3	1.1	0.7	0.7	4.6
24/12/99	1.5	0.6	0.5	0.8	4.5
25/12/99	1.2	0.9	0.6	0.6	3
26/12/99	1.1	0.9	0.6	0.6	3.6
27/12/99	1.1	0.7	0.7	0.5	2.4
28/12/99	1.2	1.6	0.7	0.8	3
29/12/99	0.8	0.8	0.8	0.7	4
30/12/99	1.0	0.9	0.8	0.6	6.4
31/12/99	1.2	0.7	0.7	0.8	3
Total	**23.3**	**18.7**	**12.7**	**15.8**	**146.7**
Average	**1.2**	**1.0**	**0.7**	**0.8**	**4.7**

Table 10, cont' d

Date	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}	$Epan_O$ mm day^{-1}
01/01/00	1.2	0.8	0.8	0.8	3.6
02/01/00	1.3	1.1	0.7	0.7	3.0
03/01/00	1.2	0.9	0.5	0.4	1.2
04/01/00	0.9	0.6	0.5	0.4	2.6
05/01/00	0.7	1.0	0.5	0.4	2.2
06/01/00	0.7	0.9	0.5	0.4	2.2
07/01/00	0.3	0.4	0.4	0.3	2.0
08/01/00	0.4	0.6	0.3	0.4	4.0
09/01/00	0.9	1.0	0.5	0.5	3.0
10/01/00	0.8	0.8	0.4	0.7	2.0
11/01/00	0.7	0.6	0.4	0.5	4.0
12/01/00	0.5	1.0	0.8	0.9	4.4
13/01/00	0.8	0.8	0.7	0.9	4.6
14/01/00	0.8	0.8	0.7	0.8	4.2
15/01/00	1.3	2.1	0.6	1.0	2.0
16/01/00	1.5	1.4	0.7	0.7	3.0
17/01/00	1.1	1.1	1.1	1.2	4.4
18/01/00	0.5	1.0	0.6	0.6	5.8
19/01/00	0.7	0.9	0.5	0.3	3.6
20/01/00	1.4	0.4	0.3	0.3	5.6
21/01/00	0.5	0.5	0.4	0.4	2.9
22/01/00	0.5	0.5	0.4	0.4	4.6
23/01/00	0.5	0.5	0.3	0.3	2.9
24/01/00	0.7	0.5	0.3	0.5	4.7
25/01/00	0.9	0.7	0.4	0.5	3.4
26/01/00	0.8	1.1	0.5	0.5	2.7
27/01/00	0.3	0.5	0.3	0.3	2.9
28/01/00	0.3	0.5	0.3	0.3	2.2
29/01/00	0.3	0.5	0.3	0.3	3.5
30/01/00	1.0	1.6	0.6	0.6	5.4
31/01/00	1.0	1.6	0.6	0.6	3.2
Total	**24.3**	**26.7**	**15.6**	**17.0**	**105.8**
Average	**0.8**	**0.9**	**0.5**	**0.5**	**3.4**

Table 10, cont' d

Date	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}	$Epan_O$ mm day^{-1}
01/02/00	0.7	1.0	0.6	0.9	2.4
02/02/00	0.6	0.6	0.3	0.5	4.0
03/02/00	1.8	0.3	0.4	0.9	4.4
04/02/00	1.1	1.6	0.7	0.8	3.8
05/02/00	1.2	2.2	0.8	0.6	3.8
06/02/00	1.5	1.1	0.4	1.3	4.0
07/02/00	1.1	1.2	0.6	1.2	3.2
08/02/00	1.8	2.1	0.8	1.3	5.8
09/02/00	1.5	0.9	1.0	1.1	8.0
10/02/00	0.9	2.3	0.8	1.2	9.0
11/02/00	1.4	2.2	0.4	0.9	3.6
12/02/00	1.4	1.2	0.7	1.0	8.2
13/02/00	1.6	1.0	0.5	1.0	1.8
14/02/00	1.0	1.0	0.3	0.6	3.6
15/02/00	0.5	0.7	0.5	1.3	2.2
16/02/00	1.3	0.9	0.5	1.3	1.9
17/02/00	0.9	1.0	0.7	0.8	1.5
18/02/00	0.3	0.4	0.2	0.8	2.0
19/02/00	1.3	1.1	0.7	0.9	5.5
20/02/00	1.2	1.4	0.5	1.0	2.1
21/02/00	0.4	0.7	0.7	0.9	2.1
22/02/00	1.3	1.0	0.5	1.0	5.1
23/02/00	1.2	1.6	0.9	0.8	3.0
24/02/00	0.9	0.7	0.7	0.9	3.0
25/02/00	1.1	1.3	0.7	1.5	3.2
26/02/00	1.3	1.2	0.8	1.3	2.2
27/02/00	1.3	1.2	0.7	1.2	2.4
28/02/00	0.8	0.9	0.6	0.9	2.0
29/02/00	1.0	0.9	0.7	1.5	2.3
Total	**32.4**	**33.6**	**17.5**	**29.5**	**106.1**
Average	**1.1**	**1.2**	**0.6**	**1.0**	**3.7**

Table 10, cont' d

Date	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}	$Epan_O$ mm day^{-1}
01/03/00	1.1	0.9	0.8	1.3	1.5
02/03/00	1.5	0.9	0.5	0.5	4.0
03/03/00	0.8	0.9	0.2	0.4	5.3
04/03/00	2.1	1.7	0.6	1.0	1.0
05/03/00	1.3	1.5	0.5	0.9	2.0
06/03/00	1.8	2.2	0.7	1.3	5.7
07/03/00	1.9	1.6	0.6	1.1	3.1
08/03/00	1.0	1.2	0.6	1.0	4.5
09/03/00	1.7	1.9	0.6	1.4	2.6
10/03/00	1.9	2.0	1.2	1.4	3.4
11/03/00	2.3	2.1	1.3	1.6	3.2
12/03/00	2.1	1.7	0.7	1.5	3.8
13/03/00	2.5	2.6	0.7	1.7	3.2
14/03/00	2.6	2.1	0.6	1.6	5.0
15/03/00	2.0	2.0	0.8	1.9	4.8
16/03/00	2.9	2.4	1.6	2.9	5.2
17/03/00	2.8	3.4	1.4	2.9	5.0
18/03/00	3.0	1.9	0.9	2.2	4.2
19/03/00	3.1	2.1	1.3	1.9	5.8
20/03/00	3.6	2.4	1.1	2.6	4.0
21/03/00	2.0	1.5	0.9	2.1	3.3
22/03/00	0.9	0.8	0.8	0.7	1.4
23/03/00	1.6	2.0	0.5	1.4	7.0
24/03/00	1.4	3.3	0.9	1.5	2.7
25/03/00	2.1	2.2	0.5	1.1	3.6
26/03/00	2.3	2.5	0.7	2.0	2.0
27/03/00	3.0	3.2	1.6	2.0	3.2
28/03/00	3.7	3.7	2.4	3.3	3.8
29/03/00	2.5	3.3	2.4	2.2	3.8
30/03/00	3.1	2.8	1.0	2.0	3.2
31/03/00	3.1	2.8	1.0	2.0	4.4
Total	**67.7**	**65.7**	**29.2**	**51.2**	**115.7**
Average	**2.2**	**2.1**	**0.9**	**1.7**	**3.7**

Table 10, cont' d

Date	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}	$Epan_O$ mm day^{-1}
01/04/00	6.2	4.6	1.9	2.5	12.2
02/04/00	3.2	5.6	3.4	3.7	7.2
03/04/00	3.8	2.9	1.3	2.6	9.0
04/04/00	4.2	3.2	1.3	2.3	6.0
05/04/00	3.6	2.7	1.8	2.6	4.4
06/04/00	3.2	2.7	0.6	2.2	7.1
07/04/00	3.7	2.6	0.6	3.1	7.1
08/04/00	4.7	3.6	2.4	3.2	4.4
09/04/00	2.5	2.5	1.1	2.5	13.0
10/04/00	2.8	2.6	1.8	2.3	10.0
11/04/00	3.9	2.1	1.6	2.9	6.0
12/04/00	2.8	2.9	0.9	1.9	5.8
13/04/00	3.0	2.4	0.8	2.9	5.2
14/04/00	3.4	3.7	3.4	2.8	5.7
15/04/00	3.4	2.5	1.4	3.7	6.3
16/04/00	3.5	2.8	2.1	3.6	6.3
17/04/00	4.0	2.9	1.5		3.7
18/04/00	3.5	3.4	1.8		9.0
19/04/00	2.6	2.0	1.2		10.0
20/04/00	4.1	2.4	1.9		7.4
21/04/00	3.0	4.4	1.9		6.8
22/04/00	3.9	4.6	1.6		9.0
23/04/00	3.5	5.2	1.7		6.8
24/04/00	3.2	4.3	1.3		5.0
25/04/00	5.6	4.6	1.6		10.4
26/04/00	4.3	5.3	1.8		6.0
27/04/00	5.5	4.5	2.1		5.3
28/04/00	5.5	4.5	2.1		9.9
29/04/00	5.2	4.0	2.6		7.4
30/04/00	4.8	3.6	1.7		6.5
Total	**116.4**	**105.0**	**51.2**	**44.8**	**218.9**
Average	**3.9**	**3.5**	**1.7**	**2.8**	**7.3**

Table 10, cont' d

Date	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}	$Epan_O$ mm day^{-1}
01/05/00	4.8	3.6	1.7		8.3
02/05/00	4.8	5.0	2.0		8.3
03/05/00	7.9	3.3	1.6		8.0
04/05/00	2.5	3.1	1.6		9.0
05/05/00	6.5	4.4	3.0		9.2
06/05/00	5.4	3.4	2.1		8.0
07/05/00	5.4	3.4	2.1		8.0
08/05/00	5.5	2.8	1.7		7.7
09/05/00	3.7	3.5	1.3		7.5
10/05/00	4.4	4.7	2.3		7.7
11/05/00	4.4	3.6	2.8		10.9
12/05/00	6.3	5.0	2.8		8.2
13/05/00	6.3	6.3	2.4		8.3
14/05/00	4.4	5.7	1.7		8.9
15/05/00	5.2	6.4	2.0		10.6
16/05/00	3.9	3.2	1.7		8.3
17/05/00	4.7	5.7	1.6		9.9
18/05/00	4.7	5.7	1.6		9.9
19/05/00	3.0	5.0	2.4		10.6
20/05/00	4.6	3.0	1.4		8.1
21/05/00	4.2	4.5	2.5		8.8
22/05/00	4.9	5.0	2.9		9.8
23/05/00	3.5	4.4	2.9		9.0
24/05/00	7.3	3.8	1.3		8.4
25/05/00	6.3	7.2	2.0		9.3
26/05/00	6.5	7.0	2.0		8.5
27/05/00	7.0	7.6	2.4		9.7
28/05/00	6.2	6.4	1.8		10.2
29/05/00	7.0	6.2	2.4		9.2
30/05/00	8.6	8.5	2.7		10.0
31/05/00	7.7	8.6	3.1		12.1
Total	**167.4**	**155.7**	**65.6**		**280.3**
Average	**5.4**	**5.0**	**2.1**		**9.0**

$Epan_G$ = evaporation rate from a pan placed in grass plastic house
$Epan_A$ = evaporation rate from a pan placed in alfalfa plastic house
$Epan_T$ = evaporation rate from a pan placed in Tomato plastic house
$Epan_C$ = evaporation rate from a pan placed in cucumber plastic house
$Epan_O$ = evaporation rate from a pan placed in open field.

Table 11. Average Class-A pan evaporation (mm day^{-1}), pan coefficients (Kp) and estimated evapotranspiration by pan (ETpan) on weekly basis in open field during the growing season, 1999/2000.

Month	Period	Ep (mm day^{-1})	Kp	ETpan (mm day^{-1})
Nov				
	22-30	4.54	0.72	3.29
Dec	1-7	7.09	0.73	5.19
	8-14	3.77	0.74	2.78
	15-21	4.46	0.70	3.13
	22-31	3.95	0.76	3.01
Jan	1-7	2.40	0.78	1.87
	8-14	3.74	0.74	2.78
	15-21	3.90	0.71	2.76
	22-31	3.55	0.77	2.73
Feb	1-7	3.66	0.73	2.65
	8-14	5.71	0.70	4.00
	15-21	2.47	0.77	1.90
	22-29	2.90	0.76	2.20
Mar	1-7	3.23	0.78	2.52
	8-14	3.67	0.73	2.67
	15-21	4.61	0.71	3.28
	22-31	3.51	0.75	2.63
April	1-7	7.57	0.72	5.48
	8-14	7.16	0.73	5.22
	15-21	7.07	0.71	5.04
	22-30	7.37	0.73	5.35
May	1-7	8.39	0.71	5.96
	8-14	8.46	0.70	5.91
	15-21	9.44	0.72	6.78
	22-31	9.63	0.73	6.99

Table 12. Average Class-A pan evaporation (mm day^{-1}), pan coefficients (Kp) and estimated evapotranspiration by pan (ETpan) on monthly basis in open field during the growing season, 1999/2000.

Month	Ep (mm day^{-1})	Kp	ETpan (mm day^{-1})
Nov	4.54	0.72	3.27
Dec	4.73	0.74	3.49
Jan	3.41	0.75	2.57
Feb	3.66	0.74	2.71
Mar	3.78	0.74	2.81
April	7.30	0.72	5.28
May	9.04	0.72	6.47
Total (mm)	1038.54	0.73	762.54
Average (mm day^{-1})	**5.27**	**0.73**	**3.87**

Table 13. Average daily evaporations on a weekly basis from Class-A pans installed inside grass($Epan_G$), alfalfa ($Epan_A$), tomatoes ($Epan_T$) and cucumbers ($Epan_C$) plastic houses, 1999/2000.

Month	Period	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}
Dec					
	8-14	1.30	0.83	0.61	0.70
	15-21	1.30	1.16	0.64	1.07
	22-31	1.16	0.89	0.70	0.68
Jan	1-7	0.90	0.82	0.56	0.48
	8-14	0.69	0.79	0.53	0.68
	15-21	1.00	1.06	0.59	0.64
	22-31	0.62	0.81	0.38	0.44
Feb	1-7	1.15	1.14	0.54	0.90
	8-14	1.37	1.53	0.63	1.02
	15-21	0.84	0.87	0.54	1.00
	22-29	1.11	1.10	0.69	1.14
Mar	1-7	1.50	1.38	0.57	0.92
	8-14	2.01	1.95	0.80	1.45
	15-21	2.77	2.25	1.14	2.35
	22-31	2.37	2.66	1.17	1.81
April	1-7	3.98	3.47	1.55	2.73
	8-14	3.29	2.83	1.72	2.86
	15-21	3.44	2.91	1.69	
	22-30	4.61	4.50	1.83	
May	1-7	5.32	3.72	2.00	
	8-14	5.00	4.52	2.13	
	15-21	4.31	4.77	1.89	
	22-31	6.50	6.47	2.35	

Table 14. Average daily evaporations on a monthly basis from Class-A pans installed inside grass($Epan_G$) , alfalfa ($Epan_A$) , tomatoes ($Epan_T$) and cucumbers ($Epan_C$) plastic houses, 1999/2000.

Month	$Epan_G$ mm day^{-1}	$Epan_A$ mm day^{-1}	$Epan_T$ mm day^{-1}	$Epan_C$ mm day^{-1}
Dec	1.23	0.98	0.67	0.83
Jan	0.79	0.86	0.50	0.55
Feb	1.12	1.16	0.60	1.02
Mar	2.18	2.12	0.94	1.65
April	3.88	3.50	1.71	2.8
May	5.40	5.02	2.12	

Table 15. Average Class-A pan coefficients (Kp) of pans inside the plastic houses on weekly basis during the growing season, 1999/2000.

Month	Period	KpG (1)	KpA (2)	KpT_G (3)	KpT_A (4)	KpC_G (5)	KpC_A (6)
Dec	8-14	0.72	1.98	1.52	2.69	1.34	2.36
	15-21	0.81	1.34	1.65	2.44	0.99	1.45
	22-31	1.11	1.74	1.85	2.23	1.89	2.27
Jan	1-7	1.65	1.87	2.66	2.75	3.07	3.17
	8-14	1.65	1.73	2.15	2.55	1.69	2.00
	15-21	0.89	1.39	1.50	2.47	1.40	2.31
	22-31	1.37	1.99	2.21	4.19	1.95	3.70
Feb	1-7	1.41	1.45	2.98	3.06	1.81	1.85
	8-14	0.98	1.31	2.13	3.20	1.31	1.97
	15-21	1.40	2.26	2.19	3.65	1.18	1.97
	22-29	1.29	1.72	2.08	2.73	1.27	1.66
Mar	1-7	1.25	1.39	3.29	3.38	2.03	2.08
	8-14	1.01	1.01	2.56	2.47	1.41	1.36
	15-21	0.76	1.09	1.85	2.15	0.90	1.04
	22-31	0.73	0.88	1.49	2.02	0.96	1.30
April	1-7	0.38	0.73	0.98	1.65	0.55	0.93
	8-14	0.63	0.89	1.21	1.47	0.73	0.88
	15-21	0.71	0.86	1.43	1.49		
	22-30	0.43	0.64	1.08	1.56		
May	1-7	0.53	0.80	1.42	1.49		
	8-14	0.56	0.61	1.32	1.30		
	15-21	0.63	0.59	1.45	1.48		
	22-31	0.36	0.35	1.00	0.95		

(1) Kp for grass plastic house **(2) Kp for alfalfa plastic house**

(3) Kp for tomato plastic house based on ET of grass

(4) Kp for tomato plastic house based on ET of alfalfa

(5) Kp for cucumber plastic house based on ET of grass

(6) Kp for cucumber plastic house based on ET of alfalfa

Table 16. Average Class-A pan coefficients (Kp) of pans inside the plastic houses on monthly basis during the growing season,1999/2000.

Month	KpG (1)	KpA (2)	KpT_G (3)	KpT_A (4)	KpC_G (5)	KpC_A (6)
Dec	0.85	1.64	1.57	2.42	1.26	1.94
Jan	1.36	1.74	2.12	2.98	1.95	2.74
Feb	1.25	1.62	2.31	3.12	1.37	1.85
Mar	0.88	1.03	2.04	2.33	1.16	1.33
April	0.51	0.75	1.17	1.54	0.71	0.94
May	0.49	0.53	1.25	1.25		

(1) Kp for grass plastic house (2) Kp for alfalfa plastic house

(3) Kp for tomato plastic house based on ET of grass

(4) Kp for tomato plastic house based on ET of alfalfa

(5) Kp for cucumber plastic house based on ET of grass

(6) Kp for cucumber plastic house based on ET of alfalfa

Table 17. weekly irrigation water electrical conductivity (ECw) for water sample collected from the inlet of the irrigation system at the experimental site at Deir-Alla Station during 1999/2000 growing season.

Month	Period	ECw (dS m^{-1})
Nov	16-21	2.6
	22-30	2.6
Dec	1-7	2.5
	8-14	2.5
	15-21	2.5
	22-31	2.5
Jan	1-7	2.5
	8-14	2.2
	15-21	2.2
	22-31	0.9
Feb	1-7	2
	8-14	1.1
	15-21	2
	22-29	1.9
Mar	1-7	1.1
	8-14	2.1
	15-21	1.9
	22-31	1.1
April	1-7	2
	8-14	2
	15-21	2
	22-30	1.9
May	1-7	1.9
	8-14	1.9
	15-21	1.9
	22-31	1.9

2- APPENDIX 2: Samples of calculations

Sample of calculations

1-Determination of potential evapotranspiration of grass (ETo) and alfalfa(ETr) in open field for given the weekly average climatic data of December of Deir-Alla located at 32 N.

Deir-Alla				
Date (weekly)	Dec 1-7			
Elevation	Z		-224	m
Minimum temperature	Tmin		13.35	°C
Maximum temperature	Tmax		24.39	°C
Mean temperature	Tmean	(Tmin+Tmax)/2	18.87	°C
Minimum relative humidity	RHmin		61.43	%
Maximum relative humidity	RHmax		85.29	%
Mean relative humidity	Rhmean	(RHmin+RHmax)/2	73.36	%
Mean atmospheric pressure	Pmean		104.76	KPa
Saturation vapour pressure at Tmax	eo(Tmax)	0.6108*EXP(17.27*Tmax/(Tmax+237.3))	3.05	kPa
Saturation vapour pressure at Tmin	eo(Tmin)	0.6108*EXP(17.27*Tmin/(Tmin+237.3))	1.53	kPa
Saturation vapour pressure at Tmean	es	[eo(Tmax)+eo(Tmin)]/2	2.29	kPa
Actual vapour pressure	ea	[eo(Tmax)*RHmin/100+eo(Tmin)*RHmax/100]/2	1.59	kPa
Vapoure pressure deficit	VPD	es-ea	0.70	kPa
Slope of saturation vapour pressure curve	Δ	2504*EXP(17.27*Tmean/(Tmean+237.3))/(Tmean+237.3)^2	0.14	$KPa\ °C^{-1}$
Virtual temperature	Tkv	(Tmean+273)*(1-0.378*ea/Pmean)^-1	293.56	K
Atmospheric density	ρ	3.486*Pmean/Tkv	1.24	$Kg\ m^{-3}$
Psychometric constant	γ	1.013*Pmean/(0.622*(2.501-(0.002361*Tmean)))/1000	0.07	$KPa\ °C^{-1}$
Latent heat vaporization	λ	2.501-(0.002361*Tmean)	2.46	$MJ\ kg^{-1}$
specific heat of moist air	C_p		1.013	$kJ\ kg^{-1}\ °C^{-1}$
Height of wind speed measurement	zm		2.00	m
Height of temperature and humidity measurement	zh		2.00	m
Roughness parameter for momentum (for grass)	zom	0.123*12/100	0.01	m
Roughness parameter for heat and water vapour	zoh	0.1*0.01 0.1*zom for grass	0.001	m
Zero plane displacement of wind profile (for grass)	do	0.67*12/100	0.08	m
Wind speed measurement at height zm	uz		2.61	$m\ s^{-1}$
Aerodynamic resistance for grass with 12 cm height	ra (grass)	((LN((zm-do)/zo))*(LN((zh-do)/(zoh))))/((0.41^2)*u)	79.56	$s\ m^{-1}$
Roughness parameter for momentum (for alfalfa)	zom	0.123*50/100	0.06	m
Roughness parameter for heat and water vapour	zoh	0.1*0.06 0.1*zom for alfalfa	0.006	m
Zero plane displacement of wind profile (for alfalfa)	do	0.67*50/100	0.33	m
Aerodynamic resistance for alfalfa with 50 cm height	ra (alfalfa)	((LN((2-do)/zo))*(LN((2-do)/(0.1*zo))))/((0.41^2)*u)	42.13	$s\ m^{-1}$
Canopy surface resistance for grass plant	rc		70	$s\ m^{-1}$
Canopy surface resistance for alfalfa plant	rc		45.00	$s\ m^{-1}$
Extraterrestrial radiation	Ra	from tables	19.21	$MJ\ m^{-2} day^{-1}$
Solar radiation	Rs		11.05	$MJ\ m^{-2} day^{-1}$
Shortwave radiation on a clear-sky day	Rso	(0.75+2*Z/100000)*Ra	14.32	$MJ\ m^{-2} day^{-1}$
Net solar short-wave radiation	Rns	0.77*Rs	11.03	$MJ\ m^{-2} day^{-1}$
Net outgoing long wave radiation	Rnl	(4.903*POWER(10;-9)*(273.16+Tmax)^4+4.903*POWER(10;-9)*(273.16+Tmin)^4)/2*(0.34-0.14*ea^0.5)*(1.35*Rs/Rso-0.35)	4.04	$MJ\ m^{-2} day^{-1}$
Net radiation	Rn	Rns-Rnl	6.98	$MJ\ m^{-2} day^{-1}$
Potential ET using P-M equation For grass crop	ETo	{(ΔRn+86.4*ρ*Cp*(VPD)/ra)/(Δ+γ*(1+rs/ra))}/λ	**2.92**	$kg\ m^{-2} day^{-1}$

2-Determination of potential evapotranspiration alfalfa(ETr) in the plastic houses for given the weekly average climatic data of December of Deir-Alla located at 32 N.

Deir-Alla				
Date (weekly)	Dec 1-7			
Elevation	Z		-224	m
Minimum temperature	Tmin		12.53	°C
Maximum temperature	Tmax		33.40	°C
Mean temperature	Tmean	(Tmin+Tmax)/2	22.97	°C
Minimum relative humidity	RHmin		33.67	%
Maximum relative humidity	RHmax		89.22	%
Mean relative humidity	Rhmean	(RHmin+RHmax)/2	61.45	%
Mean atmospheric pressure	Pmean		103.97	kPa
Saturation vapour pressure at Tmax	eo(Tmax)	0.6108*EXP(17.27*Tmax/(Tmax+237.3))	5.14	kPa
Saturation vapour pressure at Tmin	eo(Tmin)	0.6108*EXP(17.27*Tmin/(Tmin+237.3))	1.45	kPa
Saturation vapour pressure at Tmean	es	[eo(Tmax)+eo(Tmin)]/2	3.30	kPa
Actual vapour pressure	ea	[eo(Tmax)*RHmin/100 + eo(Tmin)*RHmax/100]/2	1.51	kPa
Vapoure pressure deficit	VPD	es-ea	1.78	kPa
Slope of saturation vapour pressure curve	Δ	2504*EXP(17.27*Tmean/(Tmean+237.3))/(Tmean+237.3)^2	0.17	KPa $°C^{-1}$
Virtual temperature	Tkv	(Tmean+273)*(1-0.378*ea/Pmean)^-1	296.29	K
Atmospheric density	ρ	3.486*Pmean/Tkv	1.22	Kg m^{-3}
Psychometric constant	γ	1.013*Pmean/(0.622*(2.501-(0.002361*Tmean)))/1000	0.07	KPa $°C^{-1}$
Latent heat vaporization	λ	2.501-(0.002361*Tmean)	2.45	MJ kg^{-1}
specific heat of moist air	C_p		1.031	kJ kg^{-1} $°C^{-1}$
Aerodynamic resistance	ra	$r_s = r_a \frac{\Delta}{\gamma}\left(\frac{R_n + 84.6 \rho c_p VPD / \Delta r_a}{\lambda ET} - 1\right) - r_a$	200.00	s m^{-1}
Surface resistance (mimimum rs= rL)	rs		208.51	m s^{-1}
Un adjusted rl			208.51	m s^{-1}
Conpy resistance	rc	$r_c = \frac{r_L}{0.5\,LAI}$	89.30	m s^{-1}
plant height	hc		20	cm
Additional resistance	ro	881.44*hc/100	176.29	m s^{-1}
Un adjusted surface resistance	rs1	rc+ro	265.59	s m^{-1}
Vapour pressure deficit adjusing factor	fVPD	1.2555*VPD-0.4569	1.78	
Adusted rl	rL	fVPD *rc*0.5*LAI	371.84	m s^{-2}
Canopy surface resistance with adjusted rl	rc2		159.25	s m^{-1}
Surface resistance	rs2	rc2 +ro	335.53	s m^{-1}
Net radiation	Rn		7.20	MJ m^{-2} day^{-1}
Potential ET using P-M1	ETP-M1	{(ΔRn +86.4*ρ*Cp*(VPD)/ra)/(Δ+γ*(1+rs/ra)) }/λ	3.30	kg m^{-2} day^{-1}
Potential ET using P-M2	ETP-M2	{(ΔRn +86.4*ρ*Cp*(VPD)/ra)/(Δ+γ*(1+rs/ra)) }/λ	2.69	kg m^{-2} day^{-1}
Potential ET using P-M3	ETP-M3	{(ΔRn +86.4*ρ*Cp*(VPD)/ra)/(Δ+γ*(1+rs/ra)) }/λ	2.51	kg m^{-2} day^{-2}

3- Calculation sheet for a numerical example of average daily (on weekly basis) rates of ET using Eq. (25) for Rn=8.64 MJ $m^{-2}day^{-1}$ and VPD = 2 kPa. (Table 13)

Grass Crop	Equations	Value	Unit
Rn		8.64	MJ m^{-2} day^{-1}
VPD		2.00	kPa
A	from Table 13	0.1889	kg MJ^{-1}
B	from Table 13	0.2492	kg m^{-2} day^{-1} kPa^{-1}
ET	A Rn + B VPD	2.13	kg m^{-2} day^{-1}
Radiative part	(A* Rn /ET)*100	76.61	%
Advective part	(B VPD/ET)*100	23.39	%

Alfalfa Crop	Equations	Value	Unit
Rn		8.64	MJ m^{-2} day^{-1}
VPD		2.00	kPa
A	from Table 13	0.1344	kg MJ^{-1}
B	from Table 14	0.7691	kg m^{-2} day^{-1} kPa^{-1}
ET	A Rn + B VPD	2.70	kg m^{-2} day^{-1}
Radiative part	(A* Rn /ET)*100	43.02	%
Advective part	(B VPD/ET)*100	56.98	%

Tomato Crop	Equations	Value	Unit
Rn		8.64	MJ m^{-2} day^{-1}
VPD		2.00	kPa
A	from Table 13	0.2979	kg MJ^{-1}
B	from Table 13	0.1589	kg m^{-2} day^{-1} kPa^{-1}
ET	A Rn + B VPD	2.89	kg m^{-2} day^{-1}
Radiative part	(A* Rn /ET)*100	89.01	%
Advective part	(B VPD/ET)*100	10.99	%

Cucumber Crop	Equations	Value	Unit
Rn		8.64	MJ m^{-2} day^{-1}
VPD		2.00	kPa
A	from Table 13	0.251	kg MJ^{-1}
B	from Table 13	0.2555	kg m^{-2} day^{-1} kPa^{-1}
ET	A Rn + B VPD	2.68	kg m^{-2} day^{-1}
Radiative part	(A* Rn /ET)*100	80.93	%
Advective part	(B VPD/ET)*100	19.07	%

4-Derivative and sample of calculation of r_s/r_a ratio from Eq. 27a for the grass crop inside the plastic house at Deir-Alla Station. 1999/2000

$$A = \frac{\Delta}{\lambda(\Delta + \gamma\left[1 + \frac{r_s}{r_a}\right])}$$

$$\lambda(\Delta + \gamma(1 + \frac{r_s}{r_a})) = \frac{\Delta}{A}$$

$$\Delta + \gamma(1 + \frac{r_s}{r_a}) = \frac{\Delta}{\lambda A}$$

$$\gamma(1 + \frac{r_s}{r_a}) = \frac{\Delta}{\lambda A} - \Delta$$

$$1 + \frac{r_s}{r_a} = \frac{1}{\gamma}(\frac{\Delta}{\lambda A} - \Delta)$$

$$1 + \frac{r_s}{r_a} = \frac{\Delta}{\gamma}(\frac{1}{\lambda A} - 1)$$

$$1 + \frac{r_s}{r_a} = \frac{\Delta}{\gamma\lambda}(\frac{1 - \lambda A}{A})$$

$$\frac{r_s}{r_a} = \frac{\Delta}{\gamma\lambda}(\frac{1 - \lambda A}{A}) - 1$$

Sample of calculation of r_s/r_a , r_s and r_a for grass at 25 °C mean temperature.

Tmin		17.00	°C
Tmax		33.00	°C
Tmean	(Tmin+Tmax)/2	25.00	°C
RHmin		50.00	%
RHmax		90.00	%
Rhmean	(RHmin+RHmax)/2	70.00	%
Pmean		104.76	KPa
eo(Tmax)	0.6108*EXP(17.27*Tmax/(Tmax+237.3))	5.03	kPa
eo(Tmin)	0.6108*EXP(17.27*Tmin/(Tmin+237.3))	1.94	kPa
es	[eo(Tmax)+eo(Tmin)]/2	3.48	kPa
ea	[eo(Tmax)*RHmin/100 + eo(Tmin)*RHmax/100]/2	2.13	kPa
VPD	es-ea	1.35	kPa
	2504*EXP(17.27*Tmean/(Tmean+237.3))/(Tmean+237.3)^2	0.189	KPa °C^{-1}
Tkv	(Tmean+273)*(1-0.378*ea/C14/10)^-1	300.31	K
	3.486*Pmean/Tkv	1.22	Kg m^{-3}
	1.013*Pmean/(0.622*(2.501-(0.002361*Tmean)))/1000	0.07	KPa °C^{-1}
	2.501-(0.002361*Tmean)	2.44	MJ kg^{-1}
A	from Table 13	0.1889	kg MJ^{-1}
B	from Table 13	0.2492	kg m^{-2}day^{-1}kPa^{-1}
r_s/r_a	I I	2.155	
r_a	565*A/B	428	s m^{-1}
r_s		923	s m^{-1}

5-Calculation of potential evapotranspiration using class-A pan method (ETpan) in open field at Deir-Alla Station in the central Jordan Valley during 1999/2000 growing season.

Example1	Interval weekly	Mean values of 1-7 Jan-2000		
minimum RH	RHmin		67.00	%
Maximum RH	RHmax		90.71	%
Mean RH	RHmean		78.86	%
Wind speed	u		1.34	m s^{-1}
green fetch	FET			
Pan evaporation	Epan		2.40	mm day^{-1}
Pan coefficient	Kpan		0.78	
Potential ET	ETpan	Epan*Kpan	1.87	mm day^{-1}
Example2	Interval	Mean values of 15-21 December-1999		
minimum RH	RHmin		39.86	%
Maximum Rh	RHmax		65.86	%
Mean RH	RHmean		52.86	%
Wind speed	u		2.04	m s^{-1}
green fetch	FET			
Pan evaporation	Epan		4.46	mm day^{-1}
Pan coefficient	Kpan		0.70	
Potential ET	ETpan	Epan*Kpan	3.13	mm day^{-1}

Kpan = (0.108-0.0286*u+0.0422*ln(FET))+0.1434*ln(RHmean)
- 0.000631*(LN(10))^2*LN(RHmean))

6- Calculation of class-A pan coefficient (Kp) under plastic house conditions.

Average weekly **1-7 Jan-2000**

Ginen

ETo for grass inside plastic house	1.48	mm	Measured
ETr for alfalfa insid plastic house	1.53	mm	Measured
Epan in grass plastic house	0.90	mm	
Epan in alfalfa plastic house	0.82	mm	
Epan in tomato plastic house	0.56	mm	
Epan in cucumber plastic house	0.48	mm	

Crop		Kp
Grass	ETo/EpanG	1.65
Alfalfa	ETr/EpanA	1.87

	using grass reference crop		using alfalfa reference crop	
		Kp		Kp
Tomato	ETo/EpanT	2.66	ETr/EpanT	2.75
Cucumber	ETo/EpanC	3.07	ETr/EpanC	3.17

7- Sample of calculations of ET using the empirical methods inside the plastic houses

Source of data

Location : Deir- Alla Station \ Alfalfa plastic house
Elevation : 224 m below see level
Period : December 8-14 (Weekly)

Mean Solar radiation (Rs)	= 2.02	mm day^{-1}
Extraterrestrial radiation (Ra)	= 7.68	mm day^{-1}
Mean minimum relative humidity (RHmin)	= 36.86	%
Mean maximum air temperature (Tmax)	= 27.78	°C
Mean minimum air temperature (Tmin)	= 12.62	°C
Mean actual daily sunshine hours (n)	= 5.99	hr
Mean maximum possible daily sunshine hours (N)	= 10.07	hr
Mean maximum air temperature (Tmax)	= 40	°C for wormest month in the year
Mean minimum air temperature (Tmin)	= 23	°C for wormest month in the year
Ratio of actual daily time hours to annual mean (p)	= 0.227	

(a) Haregreaves method (1977)

ETH = (0.0135*Tmean)*Rs	=	**1.03**	**mm day^{-1}**

(b) Jensen- Haise method (1963)

ETJ-H = C_T*(Tmean - T_X)* Rs	=	**1.23**	**mm day^{-1}**
C_T = 1/(C_1+ C_2*C_H)	=	0.02	
C_H = 50/(e_2-e_1)	=	1.07	
e_2 = 1.3329*$exp^{[21.07-5336/(Tmax+273.1)]}$	=	74.80	
e_1 = 1.3329*$exp^{[21.07-5336/(Tmin+273.1)]}$	=	28.12	
TX = -2.5 - 0.14* (e_2-e_1) -Elev/550	=	-8.63	
C_1= 38 - Elev/305	=	39.47	
C_2= 7.3	=	7.30	

(c) FAO Blany-Criddle (Doorenbos & Pruit, 1977)

ETB-C = {a + b*[p*(0.46*Tmean + 8.13)]}*{1+0.1*(Elve/1000)}	=	**1.45**	**mm day^{-1}**
a = 0.0043* RHmin - n/N -1.41	=	-1.27494	
b = 0.82 - 0.0041*(RHmin) + 1.07*(n/N) +0.066*(U_d) - 0.006(RHmin)*(n/N) - 0.0006*(RHmin)*(U_d)	=	0.688769	
n/N ratio = 2*Rs/Ra -0.5	=	0.023438	

ملخص

تقدير ونمذجة الاستهلاك المائي للنجيل، الخيار والبندوره تحت ظروف الزراعة المحمية في الاغوار الوسطى

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اجريت هذه الدراسه خلال الموسم الزراعي 2000/1999 في محطة مركز اقليمي ديرعلا للبحوث الزراعيه ونقل التكنولوجيا الواقعه في الاغوار الوسطى، وقد هدفت الى (ا) تقدير قيم معامل المحصول للبندورة (*Lycopersicon esculentum*) والخيار(*Cucumis sativus*) تحت ظروف البيوت البلاستيكيه باستخدام النجيل صنف برمودا (*Cynodon dactylon*) والبرسيم الحجازي (*Medicago sativa*) كمحاصيل مرجعيه. وقد هدفت هذه الدراسه أيضا الى (ب) ايجاد نموذج رياضي لتقدير الاستهلاك المائي للبندوره والخيار والبرسيم والنجيل صنف برمودا بتتبع رطوبة التربه والمعلومات المناخيه داخل البيوت البلاستيكيه. استخدمت طريقة الاستنزاف الرطوبي للتربه بواسطة جهاز (TRIME) في حساب الاستهلاك المائي للمحاصيل داخل البيوت البلاستكية.

دلت النتائج على ان الاستهلاك المائي الموسمي داخل البيوت البلاستيكيه قد بلغ 403و327 و 356 و 214 ملم للنجيل والبرسيم والبندوره والخيار على الترتيب، وقد بلغت كمية المياه المضافه 428 و 500 و 429 و 275 ملم لتلك المحاصيل على الترتيب. تراوح معدل قيم معامل محصول حسب مراحل النمو للبندوره ما بين 0.50 و 1.34 وذلك عند اعتماد النجيل كمحصول مرجعي، بينما تراوحت قيمه ما بين 0.31 و 0.91 عند استخدام البرسيم كمحصول مرجعي. اما

قيم معامل المحصول للخيار فقد تراوحت ما بين ٠,٦٧ و ١,٢٩ نسبة الى النجيل وما بين ٠,٤٦ و ٠,٨١ نسبة الى البرسيم كمحصول مرجعي. وقد تبين ان الاستهلاك المائي الموسمي المقاس للنجيل والبرسيم داخل البيوت البلاستيكيه يعادل ٤٠% من الاستهلاك المقدر باستخدام معادلة بنمان- مونتيث في الحقل المكشوف. استنبطت نماذج بسيطه لقياس الاستهلاك المائي داخل البيوت البلاستيكيه للمحاصيل المستخدمه في الدراسه تربط الاستهلاك المائي(ET) مع صافي الاشعاع الشمسي (Rn) و فرق جهد بخار الماء (VPD) بالاستناد الى معادلة بنمان- مونتيث: $ET = A Rn + B VPD$. وقد تم تقدير معدل المقاومه الديناميكيه للهواء (r_a) و مقاومة ثغور سطح الاوراق لبخار الماء (r_s) من قيم المعاملات (A) و (B). وقد بلغت قيم (r_a) ٤٢٨ و٩٩ و ٥٥٥ و ١٠٥٩ ث/م و بلغت قيم (r_s) ٩٢٤ و ٤٤٨ و ٣٩٣ و ١٥ ث/م للنجيل و البرسيم والخيار والبندوره على الترتيب. وقد بينت الدراسه استخدام معادلة بنمان – مونتيث باستعمال قيم (r_a) و (r_s) المقدره تعتبر من افضل الطرق لتقدير الاستهلاك المائي داخل البيوت البلاستيكيه مقارنة مع الطرق الحسابيه الاخرى. وقد أظهرت النتائج أيضا بان صافي الاشعاع الشمسي (Rn) من افضل العوامل المناخيه المستعمله في تقدير الاستهلاك المائي داخل البيوت البلاستيكيه.

بينت النتائج بان هنالك علاقات خطيه ما بين معدل التبخر الاسبوعي من حوض التبخر المثبت في الحقل المكشوف وبيتن تلك المثبته داخل البيوت البلاستيكيه. وجد ان, التبخر في بيوت النجيل والبرسيم والخيار والبندوره يعادل ٠,٥ و ٠,٤٧و٠,٢٢ و ٠,٣١ من تبخر الحوض الخارجي, على الترتيب. قدرت قيم معاملات احواض التبخر (Kp) الاسبوعيه والشهريه داخل البيوت البلاستيكية وتم ربطها ببعض العوامل المناخيه.