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Jiftah Ben-Asher, Bnajahu Bar-Josef, Arkadii Ginzburg, Roman Volynskyi (Agri-ecology group of the Katif Research Center, Development of Costal Deserts, Ministry of Science, Israel)

NON-FAO PENMAN-MONTEITH EQUATION COMBINED WITH MULTIPLE LINEAR REGRESSION FOR TRANSPIRATION

The important processes in the soil-plant-atmosphere system are absorption of water from the soil, its movement inside the plant and evaporation to the surrounding atmosphere. In the present work we intend to use a statistical analysis to determine the relationship between actual evapotranspiration ETA (dependent variable) and three independent variables: $CATD$, RH, and RS. As inputs for applying statistics are used observation data from the BANANA_1 and BANANA_5 fields.

Keywords: plant, atmosphere, evapotranspiration, observation data.

1. Introduction

1.1. Objectives The important processes in the soil-plant-atmosphere system are absorption of water from the soil, its movement inside the plant and evaporation to the surrounding atmosphere [1,2,3,4,5]. In the present work we intend to use a statistical analysis [6,7,8,9,10] to determine the relationship between actual evapotranspiration ETA (dependent variable) and three independent variables: $CATD$, RH, and RS. As inputs for applying statistics are used observation data from the BANANA_1 and BANANA_5 fields.

1.2. Linear and Multilinear Regression Models It is known that statistical Linear Regression Model presents the dependent variable y and the independent variable x as the regression equation given as

$$Y_i = \beta_0 + \beta_1 x_{i1} + e \quad, i = 1,2,3..., n. \tag{1}$$

As predicted by this method the best fitting line can be found by minimizing the squares of the vertical distance from each data point on the line.

Similarly the Multiple Linear Regression Model treats dependent variable in the relation to two or more independent variables.The general model for k k variables is of the form [6,7,8,9.10]:

$$Y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ...\beta_k x_{ik}, i = 1,2,..., n. \tag{2}$$

Multiple linear regression model for the case of two independent variables is used to find the plane that best fit the data.Models that deal with more than two independent variables are more complicated but still are in use to investigate more difficult problems.

1.3. Examples of Application Multilinear regression model is actively applied in the researches of the transpiration in Agri-Ecologic works. For example, it was found that multivariable linear and second order regression models with an R^2 of 0.883 and 0.889 respectively, adequately describe the effects of climate factors on actual evapotranspiration ETA of container grown $ACER\ RUBROUM$ [10].

In work [11] the model for $THORNY\ BAMBOO$ growth in Taiwan gives the equation connecting transpiration , Solar Radiation and saturated Vapor Pressure Deficit (VPD) as follows

$$Tr = -346.5 + 0.48RS + 10.91VPD. \tag{3}$$

The quantitative effects of solar radiation and vapor pressure deficit are under discussion.

The paper [12] presents results of the first study conducted in Kuwait to obtain empirical relations for the estimation of daily and monthly pan evaporation as functions of available meteorological data of temperature, relative humidity, and wind speed. The data used for the modelling are measurements within a period of 17 years of observations .Multiple linear regression technique is used with a procedure of variable selection for fitting the best model.The evaporation models were shown to produce results that are in a reasonable agreement with observation values.

The work [13] described the study carried out during the 1995 and 1996 vegetation seasons under the contrasting climate conditions of Brazil, Germany, and Israel. Corn was chosen as a common crop. It confirmed that the Penman–Monteith equation is a robust tool for daily and diurnal computations of plant transpiration under different climate conditions. Its reliability is primarily influenced by canopy resistance parameterization and accuracy of input variables.

The relationship between actual $Eact$ and potential Ep transpiration above a grass-covered forest clearing was investigated numerically and experimentally in the work [14] from simultaneous measurements of soil moisture content profiles and mean meteorological conditions. The value $\frac{Eact}{Ep}$ was found to be appro-ximately constant and insensitive to variability in near-surface soil moisture content.

2. Material and methods The study areas named for brevity BANANA_1 and BANANA_5 are located in the vicinity of the Jerusalem and Dead Sea districts of Israel. Period of observations was 06/01/2014-20/01/2014. Tests were carried out every day from 0 to 24 hours.

2.1.1. Penman-Monteith equation In this section is presented a brief description of the method used to estimate the ETA -actual evapotranspiration for banana crop in three stages.

First , ETP -potential evapotranspiration is computed by means of the Penman-Monteith (PM) equation solution. Because PM equation is of key importance in the present work, some information is attached below. The PM equation typically is written as follows :

$$ETP = \frac{\Delta(R_n - G) + \rho_a c_p (e_s - e_a)/r_a}{\lambda \rho_w (\Delta + \gamma(1 + r_s/r_a))} \tag{4}$$

where ETP-is the daily average potential evapotranspiration rate $(mmday^{-1})$, where Δ is slope of the saturation wapor-pressure curve $(kPa^{\circ}C^{-1})$; γ –is the psychrometric constant $(kPa^{\circ}C^{-1})$; R_n is net radiation $(MJm^{-2}day^{-1})$; G is the soil heat flux at the soil surface $(MJm^{-2}day^{-1})$; λ is latent heat of vaporization $(MJkg^{-1})$; ρ_a is air density (kgm^{-3}); ρ_w is the water density (kgm^{-3}); e_s is the saturated vapour pressure of the air (kPa); e_a is the actual vapour pressure $((kPa)$; $(e_s - e)_a$ is the vapor – pressure deficit ; c_p is the heat capacity of the moist air $(MJkg^{-1\circ}C^{-1})$; r_a is the aerodynamic resistance (sm^{-1}); and r_s –is the surface (canopy) resistance (sm^{-1}).

Classical PM model uses standard climatological records of air temperature, relative humidity, wind speed and net radiation. In the present work coefficients r_a, r_c are found following approach described in the work [5] . The idea of this approach can be briefly summarized as follows.Let's consider Fig. 2.1 describing course of the $CATD$ as a function of aerodynamic resistance r_{av} for various values r_c under same meteorological conditions. Evidently, there are points of minimum for $CATD$ on the graph under some critical values r_c and r_{av}. In present work above critical values r_c and r_{av} are determined numerically using above mentioned extremal property of the evaporation process and graphs similar to that depicted in the Fig. 2.2. In greater details this method is described in [5].

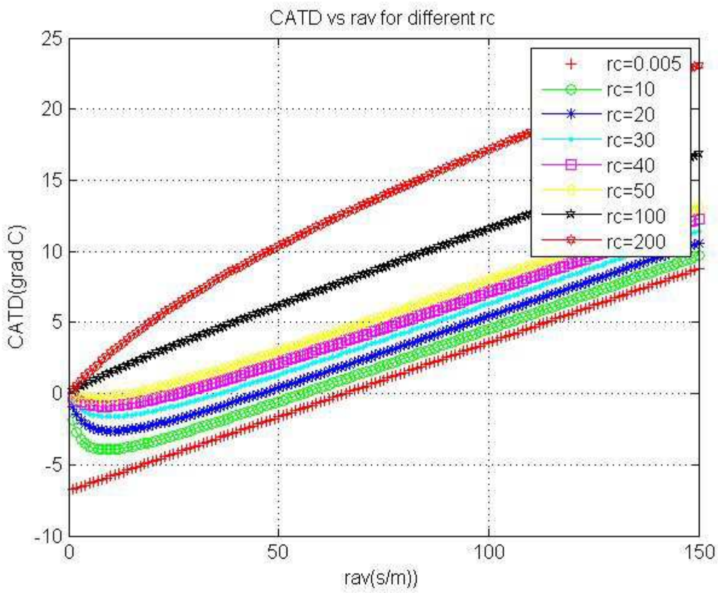

Fig. 2.1. $CATD$ as a function of r_{av} for various values of r_c. Climatological conditions are : RS =600 Wm^{-2}, VPD =2000 Pa and $T_{air} = 30^o C$

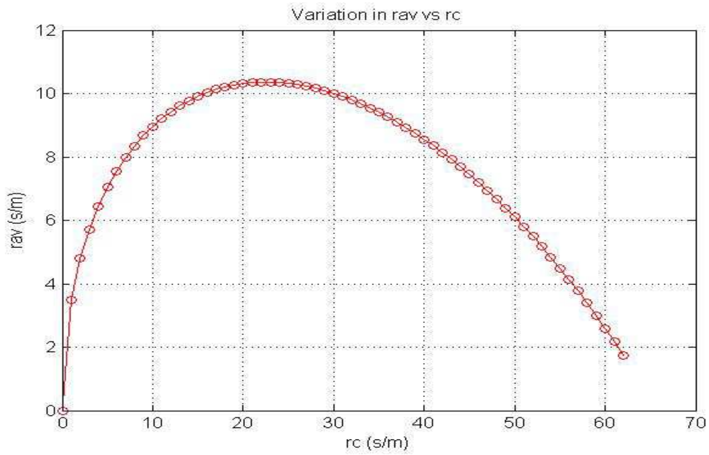

Fig. 2.2.Variations of the r_{av} vs r_c rc . Climatological conditions are : RS =600 Wm^{-2}, VPD =2000 Pa and $T_{air} = 30^o C$

2.1.2. Crop Water Stress Index and solution for ETA

$CWSI$ -crop water stress index, ranging between 0 and 1 is determined following work [4] as follows:

$$CWSI = \frac{\gamma(1 + r_c / r_a) - \gamma}{\Delta + \gamma(1 + r_c / r_a)}. \quad (5)$$

Here γ -psychrometric constant, r_c and r_a are the coefficients of the canopy resistance and air resistance,respectively which are found from the special procedure in [5] from the Penman-Monteith equation. Finally,the value of ETA is presented as:

$$ETA = CWSI * ETP. \quad (6)$$

2.2. Meteorological input The required meteorological input to compute ETP were measured by the standard observation facilities.Examples of obtained courses of parameters are presented below at the following series of figures.

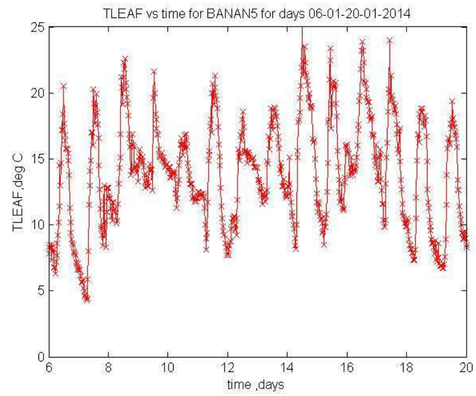

Fig. 2.2. Leaf temperature vs time for days 06-01:20-01-2014 for BANANA_5 field

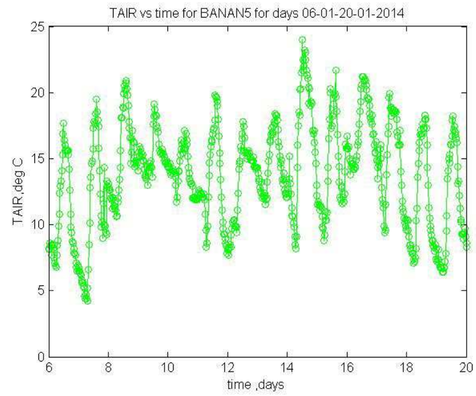

Fig. 2.3. Air temperature vs time for days 06-01:20-01-2014 for BANANA_5 field

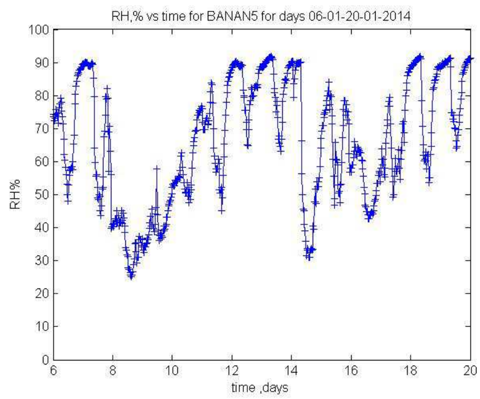

Fig. 2.4. Air humidity(%) vs time time for days 06-01:20-01-2014 for BANANA_5 field

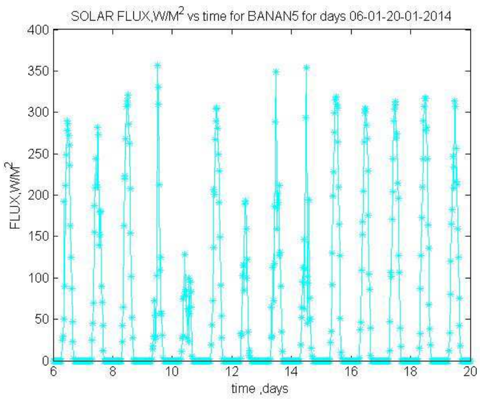

Fig. 2.5. Solar flux (Wm^{-2}) vs time for days 06-01:20-01-2014 for BANANA_5 field

Similar meteorological data are obtained for experimental field BANANA_1

3. Results and discussion

3.1. Transpiration model applied to BANANA_1 and BANANA_5 data

A computer program was written in MATLAB to calculate the ETA values on a hourly basis using the meteorological data for each area.

Calculations were performed using formulae for ETA using Penman-Monteith equation and values $CWSI$ described in chapter 2 for the input dataobtained for BANANA-1 and BANANA-5 observational fields.

Obtained ETA were analyzed by the Multiple Linear Regression Model supported by $MATLAB$ $R-2012B$ package to obtain the relationship between dependent variable ETA and independent variables $CATD, RH$ and RS prescribed by the formula (1) with the estimators $\beta_0, \beta_1, \beta_2, \beta_3$ eqal to: 0.0088, -0.0003, -0.0001, 0.0010 for BANANA_1 and 0.0234, 0.0068, -0.0003, 0.0009 for BANANA_5 , respectively.

Results of the comparison between known and fitted ETA vs time are given in the Fig. 3.1 for BANANA_1 and Fig. 3.2 for BANANA_5.

To validate the model consider graph presenting both cources on ETA known and ETA fitted by means of the Multilinear Regression software vs time. The comparisons are depicted in the Fig. 3.1 for BANANA_1 and Fig. 3.2 and for BANANA_5. The comparison between the known ETA fitted ETA A are given the Fig. 3.3 and Fig. 3.4 with coefficients $R^2{}_1$=0.9663 and $R^2{}_2$=0.9405,respectively for BANANA_1 and BANANA_5.

Therefore, present statistical approach adequately describes the influence of the meteorological conditions on the actual evapotranspiration.

Finally, a comparison was performed between the ETA (fitted) and ETP (fitted) with regards to work [15] which suggested that the relation ETA/ETP are constant values for the data under consideration. Present Fig. 3.5. gives for the relation ETA/ETP a constant value equal 0.78 and confirms conclusion made in [15].

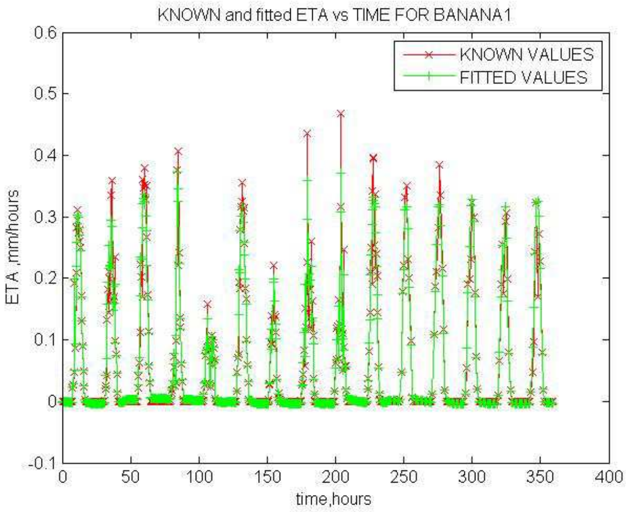

Fig. 3.1. Known and fitted ETA vs time for BANANA_1

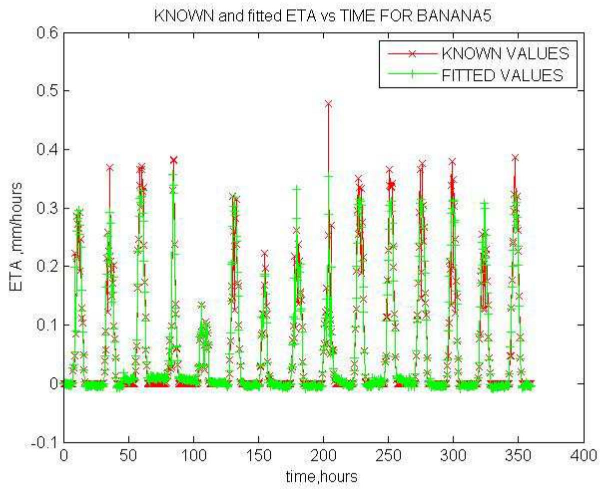

Fig. 3.2. Known and fitted ETA for BANANA-5

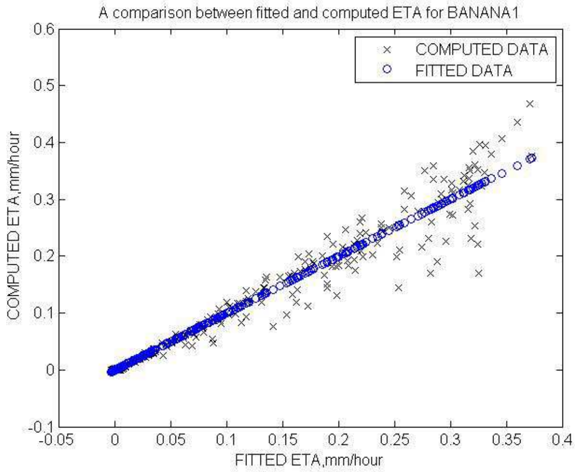

Fig. 3.3. Known ETA vs fitted ETA for BANANA_1

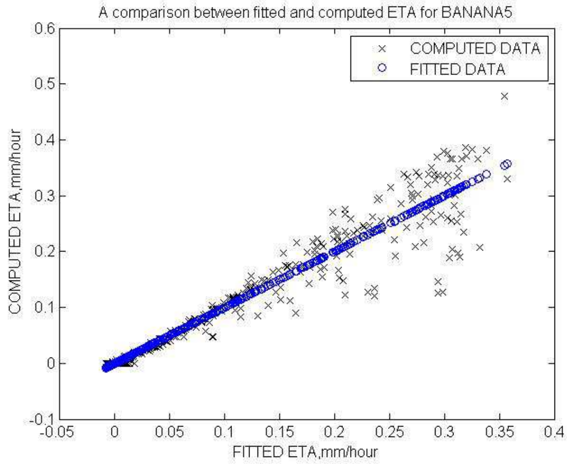

Fig. 3.4. Known ETA vs fitted ETA for BANANA-5

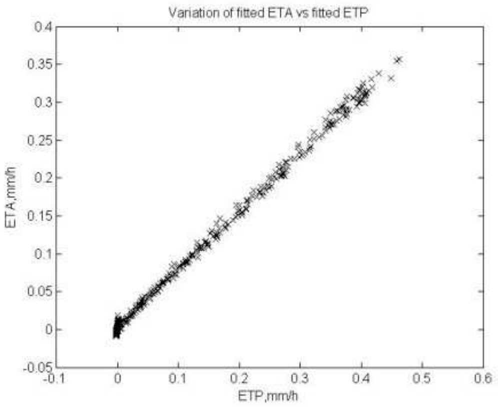

Fig. 3.5. Variation of the fitted ETA vs fitted ETP for BANANA_5.

Summary In this work combined Penman-Monteith equation and Multiple and one-linear Regression Analysis are used to determine the relationship between actual evapotranspiration (dependent variable) and three independent variables: $CATD = TLEAF - TAIR$, RH, and RS. Here $CATD$ is the canopy-air temperature differences, $TLEAF$ is the leaf temperature, TAIR is the air temperature, RH is the humidity, RS is the solar radiation. As inputs for applying statistics are field observations data BANANA_1 and BANANA_5. Measured and calculated actual transpiration rates are highly correlated with the coefficients of determination $R^2{}_1 = 0.9633$ for BANANA_1 and $R^2{}_5 = 0.9405$ for BANANA_5. The slopes of the regression lines in both Fig. 3.3 and 3.4 are close to unity. Also it is found that under prescribed conditions relation $\frac{ETA}{ETP} = 0.78$ with agreement to the main idea of work [15]. Therefore, present approach adequately describes ETA reaction on meteorologic data. Obtained results may be used in model predicting ETA for banana plants in some Israeli areas in winter. Also it may be concluded that present work needs to be continuated using as input available dataof substantial continuity coverage characterizing both droughty and rainy weather .

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Рецензент: д.т.н., професор Хлапук М. М. (НУВГП)

Джифтах Бен-Ашер, Бнаяху Бар-Йозеф, Аркадій Гінзбург, Роман Волинський
(Агро-екологічна група, Катіфський дослідницький центр по вивченню прибережних пустель, Міністерство науки, Ізраїль)

ВИКОРИСТАННЯ РІВНЯННЯ ПЕНМАНА-МОНТЕЙСА І МНОЖИННОЇ ЛІНІЙНОЇ РЕГРЕСІЇ ДЛЯ ТРАНСПІРАЦІЇ

Важливими процесами в системі “грунт-рослина-атмосфера” є поглинання води з грунту, її рухи всередині рослини і випаровування в навколишню атмосферу. У цій роботі ми маємо намір використовувати статистичний аналіз для визначення відносин між фактичною евапотранспірацією (залежною змінною) і трьома незалежнимих змінними $CATD$, RH та RS . Як входи для застосування статистики використовуються дані спостережень з полів BANANA_1 і BANANA_5.

Ключові слова: рослина, атмосфера, випаровування, дані спостережень.

Джифтах Бен-Ашер, Бнаяху Бар-Йозеф, Аркадий Гинзбург и Роман Волынский
(Агро-экологическая группа, Катифский исследовательский центр по изучению прибрежных пустынь, Министерство науки, Израиль)

ИСПОЛЬЗОВАНИЕ УРАВНЕНИЯ ПЕНМАНА-МОНТЕЙСА И МНОЖЕСТВЕННОЙ ЛИНЕЙНОЙ РЕГРЕССИИ ДЛЯ ТРАНСПИРАЦИИ

Важными процессами в системе “почва-растение-атмосфера” являются поглощение воды из почвы, ее движения внутри растения и испарения в окружающую атмосферу. В настоящей работе мы намерены использовать статистический анализ для определения отношений между фактической эвапотранспирацией (зависимой переменной) и тремя независимыми переменными $CATD$, RH и RS . Как входы для применения статистики используются данные наблюдений с полей BANANA_1 и BANANA_5.

Ключевые слова: растение, атмосфера, испарение, данные наблюдений.