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DETERMINATION OF RAINFALL-RUNOFF RELATIONSHIP BASED ON SOIL PHYSICAL PROPERTIES FOR USE IN MICROCATCHMENT WATER HARVESTING SYSTEM DESIGN[*]

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Abstract– This paper describes a subroutine for estimation of daily and average annual runoff in a computer model for microcatchment design and prediction of rain-fed grape yield in the Bajgah area, Fars province, Islamic Republic of Iran. In this subroutine, it is assumed that all abstractions arise from infiltration, and a method for determining ponding time and infiltration by using recording rain gage data and soil physical properties was developed based on the Green-Ampt infiltration equation. This subroutine was then incorporated into a previously developed model to design the microcatchment area and grape yield prediction. The developed subroutine resulted in a daily microcatchment runoff coefficient of 0.0737 in the study area which is similar to the measured value of 0.080. The daily threshold rainfall to produce daily runoff estimated by the developed subroutine was 6.5 mm where its measured value was 4.6 mm. The developed subroutine resulted in a microcatchment average annual runoff coefficient of 0.0894 in the study area, which is similar to the measured value of 0.0875. The annual threshold rainfall to produce annual runoff was estimated by the developed subroutine, and was 158.8 mm where its measured value was 106.5 mm. The estimated relationship between annual runoff and rainfall was used in the model and estimated the microcatchment area and grape yield properly. In general, it is indicated that the developed subroutine is able to determine the daily and annual runoff-rainfall relationship to be used in the model for the design of the micricatchment area and prediction of grape yield in the study area.

Keywords– Runoff sub-model, Microcatchment water harvesting system, rain-fed vineyard; Microcatchment area, Green-Ampt equation

1. INTRODUCTION

In the southern part of I.R. of Iran (Fars province) like most regions of this country, farmers are generally more concerned about the availability of water. Annual precipitation varies between about 200 mm and 750 mm with mostly less than 300 mm and drought is a common occurrence. Some of the agricultural production, especially grapes, rely on the rainfall, which tends to be concentrated mostly in the winter months when most of the crops do not need water [1].

Many other surface runoff models are available in literature. Cundy and Tendo [2] presented a semi-analytical scheme to solve the contribution of Philip-Two-Term equation (PTT) and kinematic wave for constant rainfall. KINEROS2 is a very versatile kinematic wave model available in the public domain that allows modeling of surface runoff and erosion at watershed level [3].

For estimation of runoff on slopes a model was developed to determine the relationship between infiltration and overland flow by Stomph et al. [4, 5]. Their model was scale effective and there was a difference between runoff at a point level and runoff at slope level. This difference is a function of rainfall

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duration and intensity, slope length and gradient, surface roughness and infiltration capacity [6]. They stated that when the duration of rainfall is greater than or equal to the starting time of the equilibrium phase, as is the case for most rainfall in the winter season in our study region, the scale effects are negligible [6]. Further, the microcatchments are established on slopes steeper than 5%, at which the scale effect for small slope length (about 7.0 m) might be neglected. Therefore, the scale effect can be neglected.

Microcatchment water harvesting systems (MWHS) have been used to collect surface runoff from a small catchment area and stored in the root zone of a cultivated area on rain-fed vineyards for direct consumption [7]. The results of previous study on rain-fed grape vines in Bajgah area, Fars province, had shown that the soil water under tree in each microcatchment is higher than the soil water in soil without microcatchment during the growing season [7].

The optimum characteristics of a microcatchment vary according to soil, crop and hydrological parameters [8, 9]. Simulation modeling is an appropriate alternative for the computation of the design variables [10, 11]. A computer model for design of microcatchment water harvesting systems for rain-fed vineyards was developed by Sepaskhah and Fooladmend [11]. This model was based on daily rainfall, runoff, daily actual evapotranspiration and water contribution from the deeper soil layers. In this model an empirical relationship between daily rainfall and runoff was used as determined by Sepaskhah *et al.* [9] as follows:

$$R_i=\alpha(P_i-P_o) \tag{1}$$

where R_i is daily runoff in mm; P_i is daily precipitation in mm and α and P_o are constants. A similar relationship was used by Boers *et al*. [8].The values of α and P_o depend on many parameters among which soil type, initial soil water content, and rainfall intensity are important, but were not considered in the determination of these constants. The value of α is runoff coefficient and P_o is the threshold value to start flow of runoff. The values of α and P_o can be determined by abstraction of rainfall using the infiltration equation [12]. Further, the infiltration equation of Philip [13] was used in the model proposed by van de Giesen et al. [6] as follows:

$$f_t=St^{-1/2}+K_s \tag{2}$$

where f_t is the instantaneous infiltration rate in m s^{-1} as a function of time, t in s, S is the sorptivity in m $s^{-1/2}$, and K_s is the saturated hydraulic conductivity in m s^{-1}. However, the measurement of S and K_s is time consuming and expensive and is not readily available for most soils in the study region. Therefore, another routine such as Green-Ampt was used to formulate the runoff-rainfall subroutine.

In this procedure, it is assumed that all abstractions arise from infiltration and a method for determining ponding time and infiltration under a variable intensity rainfall is developed based on the Green-Ampt infiltration equation.

The objective of this study was to develop a subroutine to determine the runoff-rainfall relationship by using recording rain gage data and soil physical properties. This subroutine was then incorporated into the model developed by Sepaskhah and Fooladmand [11] to design the MCWH systems and to predict grape yield.

2. MODEL FORMULATION

The general flow diagram of the computer model described in this paper is shown in Fig. 1. A Fortran Power Station source code has been written for this model. The daily under-tree soil water balance in the microcatchment expressed in terms of soil water depletion at the end of the day is as follows [14]:

$$D_{r,i}=D_{r,i-1}-P_i-R_i+E_{TA,i}+D_{P,i}-Q_i \tag{3}$$

where $D_{r,i}$ is the root zone depletion at the end of the day i in mm; $D_{r,i\text{-}1}$ the soil water content in the root zone depletion at the end of the previous day i-1 in mm; P_i the rainfall on day i in mm; R_i the runoff from the soil surface on day i in mm; $E_{TA,i}$ the actual evapotranspiration on day i in mm; $D_{P,i}$ the deep percolation on day i in mm, and Q_{i} is the upward water flux on day i in mm. In this study, the grape root zone is considered equal to 140 cm and the root zone is divided into seven layers each with 20 cm thickness. So, the water balance equation for the first layer is as follows:

$$D_{r,i(1)}=D_{r,i-1(1)}-P_i-R_i+E_{TA,i(1)}-Q_{i(1)} \tag{4}$$

where $D_{r,i(1)}$ is the soil water depletion from the first layer at the end of day i in mm; $D_{r,i-1(1)}$ the soil water depletion in the first layer at the end of the previous day i-1 in mm; $E_{TA,i(1)}$ the portion of actual evapotranspiration absorbed from the first layer at the end of the day i in mm and $Q_{i(1)}$ is the upward water flux from the second layer to the first layer on day i in mm. Now two conditions may occur as: (i) when $D_{r,i(1)}>0$, so the following equations can be used:

$$D_{P,i(1)}=0 \tag{5}$$

$$\theta_{i(1)}=\theta_{fc(1)}-D_{r,i(1)}/\delta Z \tag{6}$$

where $D_{P,i(1)}$is the water percolation from the first layer to the second layer on day i in mm; $\theta_{i(1)}$ the volumetric soil water content at the first layer on day i in $\mathrm{m}^3\,\mathrm{m}^{-3}$; $\theta_{fc(1)}$ the field capacity at the first layer in $\mathrm{m}^3\,\mathrm{m}^{-3}$, and δZ is the thickness of each layer (δZ=20 cm). (ii) when $D_{r,i(1)}=0$, so the following equations can be used:

$$D_{r,i(1)}=0 \tag{7}$$

$$D_{Pi(1)}=P_i+R_i-E_{TA,i(1)}-D_{r,i-1(1)}+Q_{i(1)} \tag{8}$$

$$\theta_{\mathrm{i}(1)}=\theta_{fc(1)} \tag{9}$$

The water balance equation for the second layer is as follows:

$$D_{r,i(2)}=D_{r,i-1(2)}-D_{P,i(1)}+E_{TA,i(2)}-Q_{i(2)} \tag{10}$$

where $D_{r,i(2)}$ is the soil water depletion from the second layer at the end of the day i in mm; $D_{r,i-1(2)}$ the soil water depletion in the second layer at the end of the previous day i-1 in mm; $E_{TA,i(2)}$ the portion of actual evapotranspiration absorbed from the second layer at the end of day i in mm and $Q_{i(2)}$ is the upward water flux from the third layer to the second layer on day i in mm. Furthermore, equations similar to Eqns (5)-(9) can be used for the second layer. On the other hand, the water balance equation for other layers is similar to the second layer. The following points were considered for solving the described equations:

The starting day for water balance calculations was 1 January. So, the amount of $D_{r,i-1(1)}$ to $D_{r,i-1(7)}$ were considered equal to zero for the beginning.

A new subroutine is formulated to determine the runoff produced by each rainfall event. Sum of the runoff in a day is daily runoff. Further, a relationship between daily rainfall and runoff was determined similar to that reported experimentally by Sepaskhah *et al.* [9] as follows:

$$R_i=\alpha(P_i-P_o)$$

where α and P_o were determined for the study period.

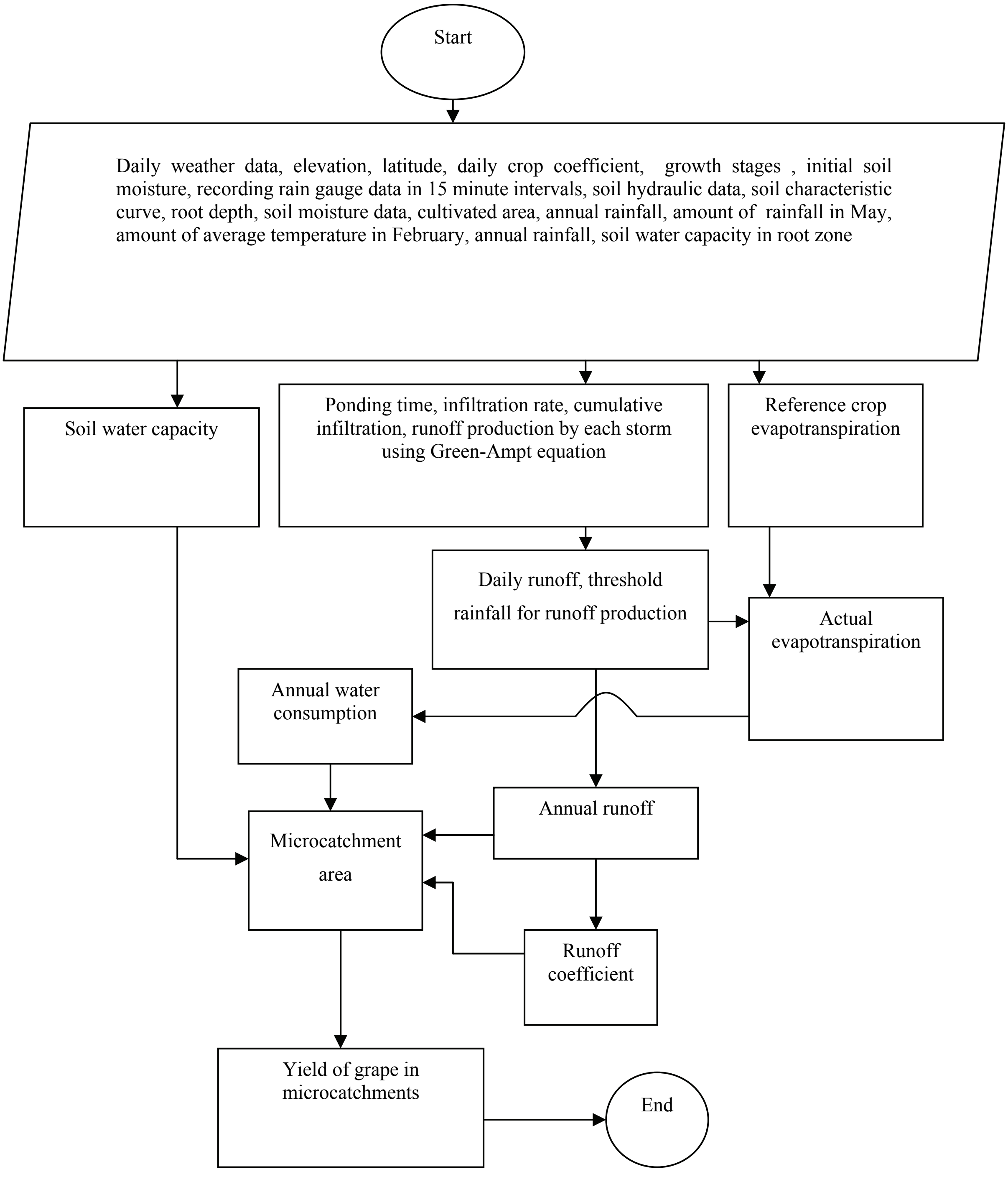

Fig. 1. General flow diagram of the computer model

The actual daily evapotranspiration during the growing season should be divided into root water uptake from different soil layers. Actual daily evapotranspiration during the active growing season was calculated by the following equations [14]:

$$E_{TA,i}=K_s\times K_c\times E_{Toi} \tag{11}$$

$$K_s=(W_{TA}-D_{rt,i\text{-}1})/(W_{TA}-W_{RA}) \tag{12}$$

$$D_{rt,i\text{-}1}=\Sigma^{j=7}{}_{j=1}D_{r,i\text{-}1(j)} \tag{13}$$

$$W_{TA}=(\theta_{fc}-\theta_{wp})Z \tag{14}$$

$$W_{RA}=P_R\times W_{TA} \tag{15}$$

$$P_R=P_T+0.045(5-E_{TA}) \tag{16}$$

where K_s is the water stress coefficient, K_c the crop coefficient, E_{Toi} the reference crop potential evapotranspiration on day i in mm; W_{TA} the total available soil water in the root zone in mm; $D_{rt,i\text{-}1}$ the total water content in the root zone at the end of the previous day i-1 in mm; $D_{r,i\text{-}1(j)}$ the water content in each soil layer at the end of the previous day i-1 in mm; θ_{fc} and θ_{wp} are the average field capacity and wilting point in the root zone, respectively (about 0.30 and 0.14 m^3 m^{-3}, respectively in the study area), Z the root zone in mm; P_R the average fraction of total available soil water (W_{TA}) that can be depleted from the root zone before stress occurs, and P_T is a fixed value of this coefficient which varies for different plants and for grape it is considered to be 0.45 [14]. The growing season for grape in the study area was considered from 21 March (80th day of year) to 22 September (265th day of year). Furthermore, the length of crop development stages for initial, developed mid and late periods were 30, 60, 40 and 55 days, respectively and crop coefficient for initial, mid and end stages were selected to be 0.3, 0.7 and 0.45, respectively [14].

For the dormant season, evepotranspiration consists only of soil surface evaporation. Therefore, instead of using Eqns (11)-(16), the following equation can be used [15]:

$$E_{TA,i}=K_e\times E_{To,i} \tag{17}$$

where K_e is the coefficient of evaporation from the soil surface that was considered equal to 0.3 [15]. Furthermore, during the dormant season $E_{TA,i(1)}$ and $E_{TA,i(2)}$ to $E_{TA,i(7)}$ are considered zero. The dormant season for grape in the study area was considered from 23 September (266th day of year) to 20 March (79th day of next year).

On the other hand, for calculating reference crop potential evapotranspiration, Penman-FAO [15] was used. This method is most appropriate for the study area as reported by Sepaskhah and Fooladmand [11]. Then, for calculating daily water uptake from each soil layer the root water uptake distribution of 40, 30, 20, 10% was used [16]. Regarding this distribution, we divided the actual daily evapotranspiration into the water uptake in different soil layers (the first to the seventh layers, i.e. $E_{TA,i(1)}$ to $E_{TA,i(7)}$ by using a ratio of 7/28, 6/28, 4/28, 3/28, 2/28 and 1/28 of $E_{TA,i}$, respectively.

a) Green-Ampt equation

It is assumed that all abstractions arise from infiltration, and a method for determining the ponding time and infiltration under a variable intensity rainfall is developed based on the Green-Ampt infiltration equation. The problem considered is: given a rainfall hyetograph defined using the pulse data representation, and the physical parameters of soil for Green-Ampt equation, determine the ponding time, the infiltration after ponding occurs, and the excess rainfall hyetograph.

In the absence of ponding, cumulative infiltration is calculated from cumulative rainfall, the potential infiltration rate at a given time is calculated from the cumulative infiltration at that time; and ponding has occurred when the potential infiltration rate is less than or equal to the rainfall intensity.

Consider a time interval from t to $t+\Delta t$. The rainfall intensity during this interval is denoted i_t and is constant throughout the interval. The potential infiltration rate and cumulative infiltration at the beginning of the interval are f_t and F_t, respectively, and the corresponding values at the end of the interval are $f_{t+\Delta t}$, and $F_{t+\Delta t}$. It is assumed that F_t is known from given initial conditions or previous computation.

A flow chart for determining ponding time is presented in Fig. *2*. There are three cases to be considered: (1) ponding occurs throughout the interval; (2) there is no ponding throughout the interval;

and (3) ponding begins part-way through the interval. The infiltration rate is always either decreasing or constant with time, so once ponding is established under a given rainfall intensity, it will continue. Hence, ponding cannot cease in the middle of an interval, but only at its end point, when the value of the rainfall intensity changes.

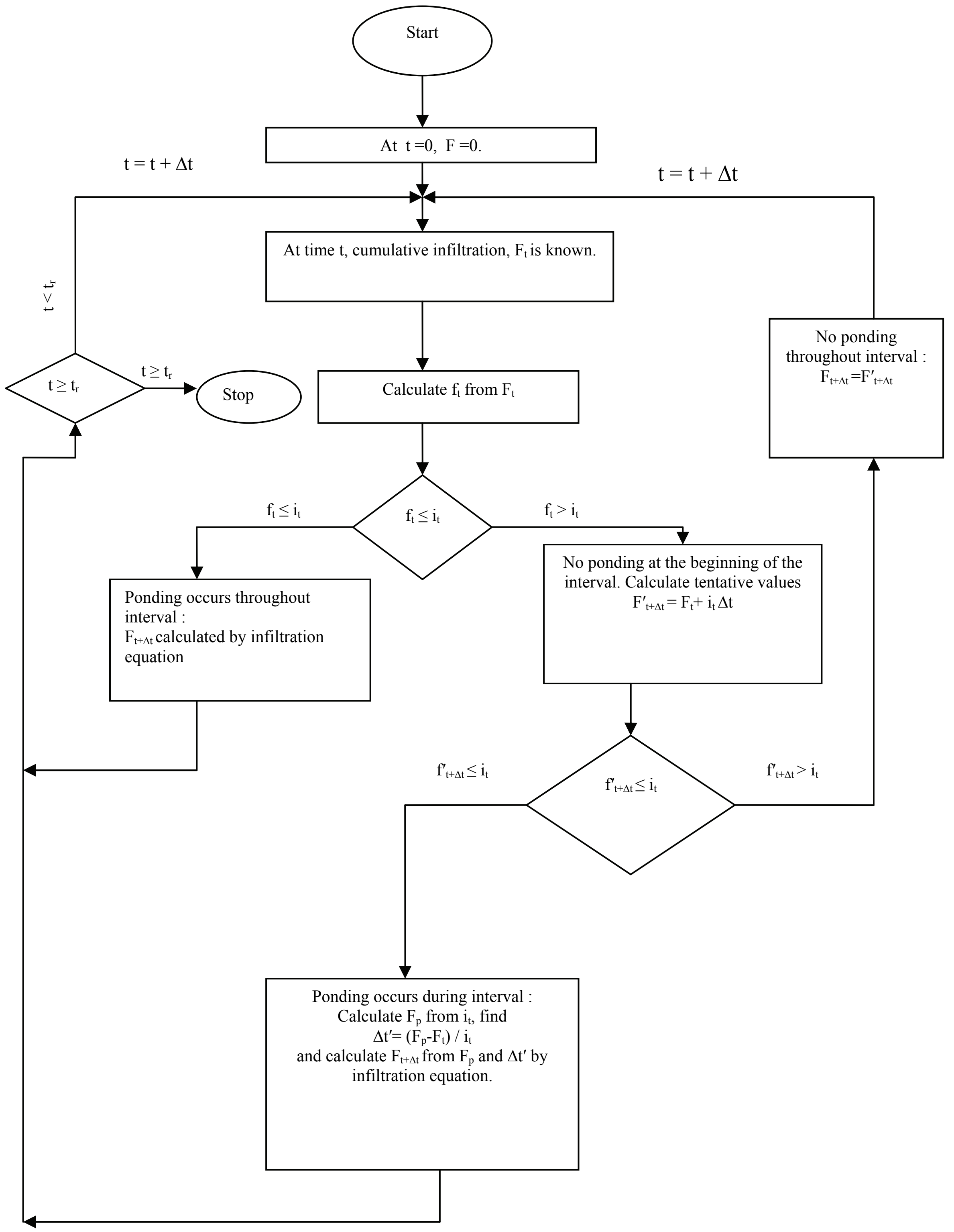

Fig. 2. Flow chart for a subroutine for determining ponding time

Following the flow chart, the first step is to calculate the current potential infiltration rate f_t from the known value of cumulative infiltration F_t. For the Green-Ampt method, one uses:

$$f_t=K(\psi\Delta\theta/F_t+1) \tag{18}$$

where, f_t is the infiltration rate at time t in cm s^{-1}, ψ is the soil water suction head at wetting front in cm, $\Delta\theta$ is the difference between soil initial volumetric water content and field saturated water content in cm^3 cm^{-3}, and F_t is the cumulative infiltration at time t in cm.

The result f_t is compared to the rainfall intensity i_t. If f_t is less than or equal to i_t, case (1) arises and there is ponding throughout the interval. In this case, for the Green-Ampt equation, the cumulative infiltration at the end of the interval, $F_{t+\Delta t}$, is calculated from:

$$F_{t+\Delta t}-F_t-\psi\Delta\theta\mathrm{Ln}[(F_{t+\Delta t}+\psi\Delta\theta)/(F_t+\psi\Delta\theta)]=K\Delta t \tag{19}$$

This equation is derived in a manner similar to that given by Chow *et al.* [12].

Both cases 2 and 3 have $f_t>i_t$ and ponding at the beginning of the interval. Assume that this remains so throughout the interval; then, the infiltration rate is i_t and a tentative value for cumulative infiltration at the end of time interval is:

$$F'_{t+\Delta t}=F_t+i_t\Delta t \tag{20}$$

Next, a corresponding infiltration rate $f'_{t+\Delta t}$ is calculated from $F'_{t+\Delta t}$. If $f'_{t+\Delta t}$ is greater than i_t, case 2 occurs and there is no ponding throughout the interval. Thus $F_{t+\Delta t}=F'_{t+\Delta t}$ and the problem is solved for this interval.

If $f'_{t+\Delta t}$ is less than or equal to i_t, ponding occurs during the interval (case 3). The cumulative infiltration F_p at ponding time is found by setting $f_t=i_t$ and $F_t=F_p$ in Eq. (18) and solving for F_p to give, for the Green-Ampt equation,

$$F_p= K\psi\Delta\theta/(i_t-K), \qquad (i_t>K) \tag{21}$$

The ponding time is then $t+\Delta t'$, where

$$\Delta t'=(F_p-F_t)/i_t \tag{22}$$

and the cumulative infiltration $F_{t+\Delta t}$ is found by substituting $F_t=F_p$ and $\Delta t=\Delta t-\Delta t'$ in Eqn (19).

b) Physical parameter for Green-Ampt equation

One of the physical parameters for Green-Ampt equation is mean soil water suction at the wetting front, ψ. The value of ψ is calculated based on the procedure presented by Clapp and Hornberger [17] as follows:

$$\Psi=\psi_e/a[K_r(\theta_{fs})^a-K_r(\theta_i)^a]/[K_r(\theta_{fs})-K_r(\theta_i)] \tag{23}$$

where ψ_e is air entry suction, θ_{fs} is the field saturated volumetric soil water content, θ_i is the initial soil water content, K_r is the relative soil hydraulic conductivity, and a is calculated as follows:

$$a=(b+3)/(2b+3) \tag{24}$$

where b is the power of the equation for the soil water retention curve as follows:

$$h=A\theta^{-b} \tag{25}$$

where h is the soil water suction, θ is the volumetric soil water content, and A and b are constants. When b is determined for the desorption condition it should be divided by 1.6 to estimate the value of b for adsorption conditions. The value of K_r is determined by the following equation:

$$K_r(\theta)=K(\theta)/K_s(\theta/\theta_s)^{2b+3} \quad (26)$$

where $K(\theta)$ is the unsaturated soil hydraulic conductivity at soil water content (θ), K_s is the saturated hydraulic conductivity at saturated water content (θ_s). The values of θ_{fs} are considered as $0.8\theta_s$ and $0.9\theta_s$ for sandy and clay soils, respectively.

Another input for runoff subroutine is $\Delta\theta$ or the difference between the field saturated and initial soil water contents in the soil surface layer (0-20 cm). The value of $\Delta\theta$ for each rain event is variable, therefore, it should be estimated for different rain events using the soil water balance in the soil surface layer. The water balance starts from the beginning of the rainy season in autumn with no transpiring vegetation on the soil surface, therefore, the $\Delta\theta$ for the first rain event may be estimated by the following equation:

$$\Delta\theta=\theta_{fs}-1/2\theta_{pwp} \quad (27)$$

where θ_{pwp} is the volumetric soil water content at permanent wilting point. The values of cumulative infiltration, runoff and ponding time are calculated by using the following equation:

$$t_p=F_p/i \quad (28)$$

$$F-F_p-\psi\Delta\theta\mathrm{Ln}[(\psi\Delta\theta+F)/(\psi\Delta\theta+F_p)]=K(t-t_p) \quad (29)$$

where F is the cumulative infiltration, F_p is the cumulative infiltration at ponding, i is the rainfall intensity, t is the elapsed time and t_p is the ponding time.

The water content of the soil surface after each rain event increases. When the rainfall duration is longer than the ponding time, the water content of the soil surface reaches the field saturation ($\theta_{as}=\theta_{fs}$), otherwise, the soil water content at the end of the rain event is estimated as follows:

$$\theta_{as}=\theta_{bs}+F_j/L_s \quad (30)$$

where θ_{as} and θ_{bs} are the volumetric soil water contents at the end and before the j^{th} rainfall event, respectively, F_j is the cumulative infiltration of the j^{th} rainfall event, and L_s is the thickness of soil surface layer taken as 20 cm in this study. When the interval between rainfall events is longer than one day, the θ_{bs} is estimated by the water balance at the soil surface with no transpiring plant as:

$$D_{si}=D_{s(i-1)}+E_{si}+D_{Ps,i} \quad (31)$$

where D_{si} and $D_{s(i-1)}$ are the water depletion from the soil surface at the end of day i and i-1, respectively, E_{si} is the evaporation from the soil surface at the end of day i and $D_{Ps,i}$ is the water percolation below the soil surface on day i. Therefore, the θ_{bsj} is estimated as:

$$\theta_{bsj}=\theta_{as(j-1)}-D_{si}/L_s \quad (32)$$

The value of evaporation from the soil surface was estimated from the following equation [18]:

$$E_s=mt^n-m(t-1)^n \quad (33)$$

where E_s is the daily evaporation from the soil surface, t is the elapse time after soil wetting, day, m and n are constants. The value of m was 0.5 and the value of n was soil dependent (0.2-0.4) and was considered as 0.2 after calibration.

Water percolation in the soil surface (loam soil) was considered during two days after the soil water content rose to field capacity and its value was estimated as:

$$D_{Ps,i}=(\theta_{asj}-\theta_{fc})L_s \qquad \text{for } (\theta_{asj}>\theta_{fc}) \tag{34}$$

c) Determination of microcatchment area

To determine the microcatchment area the following equations can be used for squared microcatchments, and for greater vegetation cover purposes, a smaller area may be selected for design. By using a smaller microcatchment area, the number of trees in each unit area (ha) increases and it may be more appropriate. These equations are as follows [19, 20, respectively]:

$$A_c=A_f+[(C_U-P_m)A_f]/(\eta P_m) \tag{35}$$

$$A_c=A_f+A_f\times D\times d/(\eta P_m) \tag{36}$$

where A_c is the microcathment area in m^2; A_f the cultivated area in m^2; C_U is the annual water consumption (actual evapotranspiration) of the plant in mm; P_m the annual rainfall in mm; η the annual runoff coefficient, D the active root depth in m and d is the soil water holding capacity in mm/m. For calculating the annual water consumption of the plant, (C_U), the following equation was used:

$$C_U=\Sigma^{i=365}{}_{i=1}E_{TA,i} \tag{37}$$

d) Yield estimation

An empirical equation for the estimation of grape yield in the study area was used [7]. This equation is as follows:

$$Y_a=373.5+2.41(P_y+R_{y(inf)})+19.8P_A-341T_F \tag{38}$$

where Y_a is the yield of each tree in g per tree; P_y the annual rainfall in mm; $R_{y(inf)}$ the infiltrated annual runoff into the root zone in mm; P_A is the amount of rainfall in April in mm and T_F is the February mean air temperature in ˚C. Infiltrated a runoff into the root zone ($R_{y(inf)}$) can be calculated from the following equation:

$$R_{y(inf)}=[R_y(A_c-A_f)]/A_f \tag{39}$$

where R_y is the amount of runoff in April in mm. A relationship between annual rainfall and runoff in the study area similar to that reported by Sepaskhah and Fooladmand [11] was determined as follows:

$$R_y=A(P_y-B) \tag{40}$$

where A is the average annual runoff coefficient and B is the threshold of annual rainfall.

3. MATERIALS AND METHODS

Ten Basins (6.7 m×2.0 m) were separated by ridges of 0.2-0.25 m in height, on foothill slopes, with an average surface slope of about 5-6% at the agricultural experiment station of Shiraz University, 16 km north of Shiraz, Fars province, I.R. of Iran. The station is located at a latitude of $29^\circ\ 50'$ N, longitude of $52^\circ\ 46'$ E and elevation of 1810 m (MSL). The most typical soil on the foothill area is the Bamoo series. This soil series contains 46% sand, 41% silt and 13% clay in a depth of 0-15 cm and 49% sand, 35% silt and 21% clay in a depth of 15-50 cm [21]. The average soil volumetric water content at field capacity and permanent wilting point were 30 and 14%, respectively.

The basins were constructed in a northeast-southwest direction. The flow of the runoff in these basins was guided to a shallow pot under the tree canopy. A similar experimental layout was used for rainfall runoff measurement. The flow of runoff in these basins was guided to a sunken barrel through a PVC tube of 50 mm (i.d.). The volume of the runoff was measured by pumping out the water from the barrels, by the use of a hand pump, after each daily runoff produced from rain during the water year 1982/83-1986/87.

The rainfall data was collected by a daily rainfall gage and a recording rainfall gage (tipping bucket type, Model 71, Type QAC, Leopold and Stevens Inc., Beaverton, Oregon, U.S.A) in a weather station located at a distance of about 500 m. The recording rainfall data was collected in 15 min intervals during 1982/83-1986/87 except for 1985/86, during which the gage was out of order and data was not available. These data for each rainy day were used in the subroutine of the model to determine the daily runoff for each rainy day. Further, there are many recording rain gage stations in arid and semi-arid regions of Iran, therefore, their data can be used to model the daily runoff in these regions.

At harvest, the average grape yield per tree at microcatchment water harvesting basins was determined [7].

4. RESULTS AND DISCUSSION

a) Runoff subroutine calibration

For runoff subroutine calibration, a surface soil layer of 20 cm with an initial water content of one half of θ_{pwp} was used. The θ_{pwp} of the soil was considered as 0.15 m^3 m^{-3}. The measured values of daily runoff were compared with those estimated by the runoff subroutine of the model. The results are shown in Fig. 3. The relationship between the measured and estimated values is as follows:

$$R_{de}=0.9922R_{dm}-0.0024, \quad R^2=0.74 \tag{41}$$

where R_{de} and R_{dm} are the estimated and measured daily runoff (mm), respectively. This equation is compared with a line of 1:1 in Fig. 3. The values of slope and intercept are not different statistically from 1.0 and 0. Therefore, it is indicated that the runoff subroutine simulated the daily runoff with appropriate accuracy.

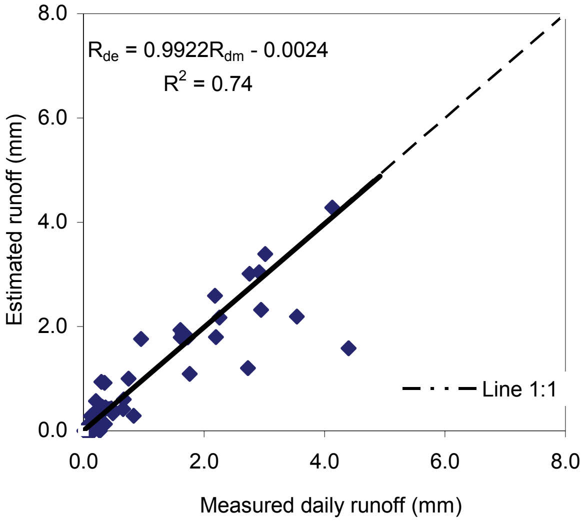

Fig. 3. Relationship between measured and estimated daily runoff by the model

By using the estimated daily runoff, the relationship between daily rainfall and estimated runoff was determined as follows (Fig. 4):

$$R_{de}=0.0737(P_d-6.5), \quad R^2=0.66 \tag{42}$$

where P_d is the daily rainfall (mm). The relationship between measured daily runoff and rainfall for the study area is as follows as reported by Sepaskhah and Fooladmand [11]:

$$R_{de}=0.080(P_d-4.6) \tag{43}$$

which is similar to Eq. (42). Their slopes (daily runoff coefficient, i.e., 0.0737 vs. 0.080) and threshold rainfall (6.5 vs. 4.6 mm) are nearly equal. Therefore, it is indicated that in the case in our study the scale effect can be negligible. However, in cases when the scale effect is not negligible the procedure for runoff determination presented by van de Giesen et al. [6] is suggested in which a scale factor should be used.

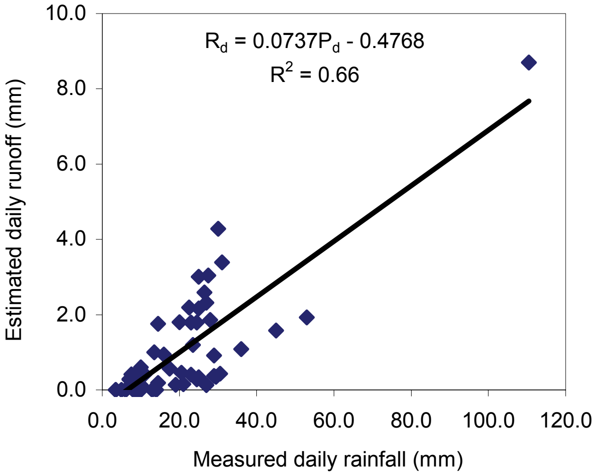

Fig. 4. Relationship between estimated daily runoff and measured rainfall

The linear relationship between the estimated annual runoff and rainfall is as follows (Fig. 5):

$$R_{ey}=0.0894(P_y-158.8), \qquad R^2=0.83 \tag{44}$$

where R_{ey} and P_y are the estimated annual runoff and annual rainfall in mm, respectively. The relationship between the measured annual runoff and annual rainfall is as follows as reported by Sepaskhah *et al.* [9]:

$$R_{em}=0.0875(P_y-106.5) \tag{45}$$

which is similar to Eq. (44). Their slopes (average annual runoff coefficients, i.e., 0.0894 vs. 0.0875) and annual threshold rainfall (158.8 vs. 106.5 mm) are nearly equal.

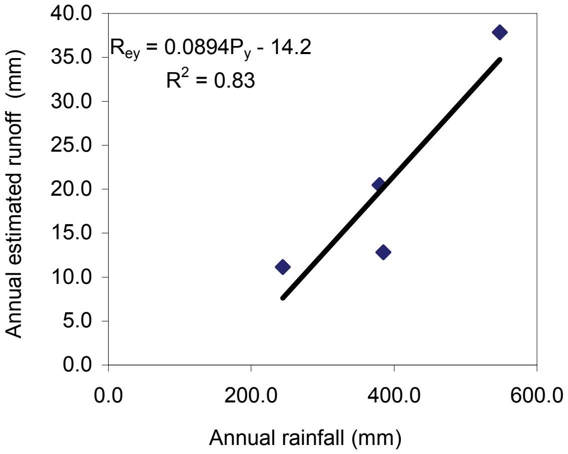

Fig. 5. Relationship between estimated annual runoff and measured rainfall

b) Model application

In the study area, active root depth for grape tree was considered to be 1.2 m, and soil water holding capacity was taken as 160 mm m^{-1}. The annual runoff coefficient for the gravelly soil in the study area with an average slope of 5-6% was 0.0894 (Eq. 44). The average diameter of mature tree canopy was considered as 1.5 m, so the cultivated area for each tree is 1.8 m^2. With the measured annual rainfall during the study years, microcatchment area was estimated according to Eq. (36). On the other hand, by using water balance model in different years and considering Eq. (35), according to the Penman-FAO method [11] for calculating the amount of annual water consumption of plant C_U, the microcatchment area was estimated. The results are presented in Table 1. This table indicated that by using Eq. (35) the estimated microcatchment area in years 1983/84 and 1985/86 is smaller than the area allocated to each tree by the planting spaces between tree rows and distances between the trees on each row (3 m×3 m=9 m^2). Therefore, the smallest micricatchment area should be 9 m^2, and it seems that Eq. (36) is more appropriate in designing the microcatchment area.

By using Eq. (38) total yield as kg ha^{-1} was estimated by the model with a microcatchment area of 13.4 m^2 and the results were compared with the measured total yield. The estimated and measured yields are compared in Fig. 6. The relationship between the estimated and measured yields is compared with the line of 1:1 in Fig. 6. The relationship between the estimated and measured yields is as follows:

$$Y_e = 0.6Y_m + 308, \qquad R^2 = 0.73 \tag{46}$$

where Y_e and Y_m are the estimated and measured yields, respectively. The slope and intercept of the line were not different statistically from 1.0 and 0.

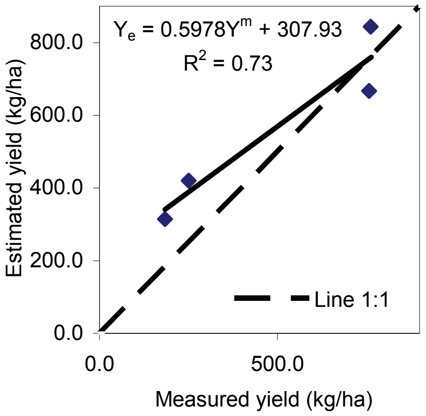

Fig. 6. Relationship between measured and estimated yield by the model

Table 1. Estimated microcatchment area in different years based on soil water capacity [Eqs. (36)] and plant water consumption [Eq. (35)]

Year	*Annual Rainfall, mm*	*Microcatchment area, m^2, based on*		*Selected design area, m^2*
		Soil water capacity	*Plant water consumption*	
1982/83	385.0	11.9	11.7	11.7
1983/84	244.0	17.7	22.1	17.7
1984/85	379.5	12.0	6.2	9.0
1986/87	548.0	8.9	1.0	9.0

5. CONCLUSION

Green-Ampt concept was used in a subroutine to determine the runoff-rainfall relationship by using recording rain gage data and soil physical properties. The developed subroutine resulted in a daily microcachment runoff coefficient of 0.0737 in the study area which is similar to the measured value of 0.080. The daily threshold rainfall to produce daily runoff estimated by the developed subroutine was 6.5 mm where its measured value was 4.6 mm. The developed subroutine resulted in a microcatchment average annual runoff coefficient of 0.0894 in the study area, which is similar to the measured value of 0.0875. The annual threshold rainfall to produce annual runoff was estimated by the developed subroutine as 158.8 mm where its measured value was 106.5 mm. The estimated relationship between annual runoff and rainfall was used in the model and estimated the microcatchment area and grape yield properly. In general, it is indicated that the developed subroutine is able to determine the daily and annual runoff-rainfall relationship to be used in the model for design of the micricatchment area and prediction of grape yield in the study area.

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