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Assessment and Simulation of Evaporation Front Depth and Intensity from Different Soil Surface Conditions Regarding Diverse Static Levels

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Abstract

The knowledge about soil evaporation is essential for improving water productivity (WP) in water-limited regions. Evaporation front (EF) depth and intensity (EI) are the most important components of agricultural activities and environmental issues, the physical characteristics of soil play a significant role in these fields. One of the key elements in physical soil properties is the relationship between the depth of the static surface and evaporation from the soil surface, especially in arid and semi-arid regions. In these regions, due to over-irrigation, the water level is very close to the ground surface which leads to salinization of the soil. The same situation may also be observed on the banks of lakes and rivers. In the present study, the EF depth and the EI of three different types of soil textures including sandy loam, loam, and clay loam are simulated in 30 cm, 40 cm, 70 cm static levels by using Gardener model. The findings of the study reveal that after 77 days, the EF depths were 6.14, 7.85, and 13.86 cm for sandy loam soil, 5.23, 7.27, and 12.2 cm for loam soil, and 5.4, 7.2, and 10.9 cm for clay loam soil in three static levels (i.e. 30, 40, and 70 cm), respectively. The deeper the static level, the deeper the depth of EF. Simulation of EF depth for sandy loam soil regarding loam and clay loam soils have more correspondence with the measured depth of the evaporation front. The measured and simulated amounts of EF depth and EI in three soil textures with three water levels were stabilized and compared by the F-statistical test models. Comparing the evaluated data of EF with the simulated figures of the evaporation front in textures and diverse static levels using the statistical test showed that a one to one line at a significant level of 5% is suitable for sandy loam soil.

Keywords: Evaporation Front; Soil Physical Characteristics; Static Levels; Water Productivity.

INTRODUCTION

Having sufficient information on soil physics-which includes properties of solid, liquid, and gas phases of a soil mixture plays a vital role in recognizing some important processes in agriculture and the environment. When agricultural issues are concerned, the soil should be a suitable substance for growing crops and plants; in this respect, it should contain suitable chemical elements as well as a proper physical structure (e.g. efficient moisture and void ratio). Taking into account arid and semi-arid areas, most watersheds lack vegetation, and as a result, evaporation occurs directly from the soil surface. The issue of direct evaporation from the soil surface is very important because it should be differentiated from the evapotranspiration phenomenon. Unlike the evapotranspiration phenomenon, which has several advantages to plant growth, soil evaporation does not have any benefits for plant production, therefore, soil evaporation measurement/ estimation in agriculture is essential since it has an effective role in increasing water consumption. The required conditions for evaporation from soil surface are (i) existence a continuous thermal source (one-gram water needs 540 cal heat to evaporate),

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(ii) gradient of vapor flow intensity, and (iii) presence of water resources in the soil (Penman 1948; Gardner 1958; Liu and Zhan. 2017).

In the steady-state, the rate of water loss from the bottle next to the soil column is equal to the rate of evaporation from the soil surface. In a non-steady-state, the evaporation rate from the soil surface is equal to the total loss of water from the water level, and the water is lost from the soil profile. At the beginning of the process, evaporation has constant intensity. Then, evaporation follows descending order. The second stage is evaporation from soil surface may be one-dimensional (soil with no lining and holes) and multi-dimensional (soil with lining and holes). This evaporation occurs in constant and non-constant temperatures. The third stage is the residual evaporation of low intensity, which begins after excessive drying of the surface layer of the soil. It is independent of day and night, but it is not constant in the free air of the soil surface temperature. The conditions of stability and un-stability in the soil are effective on evaporation. If soil is non-stable, rainfall changes the condition of the surface soil. This change is different from that of stable soil and makes some changes in evaporation. The relationship between the static surface depth and soil surface evaporation is quite important in most arid and semi-arid areas. In these areas, due to extra irrigation, the static level is close to the ground and creates soil salinity. This condition can be observed in the banks of rivers and lakes. Proper management is needed for preserving (Liu et al. 2016). Those rare resources are underground water and avoiding the salinity of low lands. In both cases, having good knowledge about the evaporation rate from the static level is essential. The amount of air evaporation is quite high in arid and semi-arid areas and it is more than soil capacity in conducting water in the liquid phase (Gowing et al. 2006). Discontinuity of the liquid-gas phase known as Evaporation Front (EF) is located in depths between the static level and the soil surface (Rose et al. 2005; Konukcu et al. 2004; Chari and Afrasiab. 2019). Above the EF, a gradient of vapor flow intensity close to the soil surface transfers water vapor toward the soil surface. In this condition, it is impossible to use Richard Equation for soil water movement for the whole soil profile (Gardner 1958; Elrick et al. 1994; Gowing et al. 2006; Sadeghi et al. 2012), whereas it is usually used for soil water movement in liquid phase or simulation and analysis models. It is essential to consider both vapor and liquid phases for describing water and vapor movement from the static surface. Therefore, the soil profile is divided into two layers (Konukcu et al. 2004): in the lower water layer, it moves in liquid form, and in layers closer to the ground, it changes into a vapor. Numerous models are used for the purpose in which the most known one is the Gardner model (Ripple et al. 1972). In this research, two simulation and evaluation methods are used for achieving the depth of the evaporation front and the evaporation intensity in different soil textures and static levels. To the knowledge of the authors, these methods have not previously been applied in this region.

MATERIALS AND METHODS

For evaluating and simulating the EFD and EI of three types of soil texture (i.e. loam, sandy loam, and clay) with different static level depths were used, and their properties are given in Table 1. The location of this greenhouse test of the irrigation group was agricultural, Shiraz (Iran) and it lasted for 80 days. During controlling changes in the greenhouse temperature, the minimum rate was 7 C and the maximum rate was 43 C. First, soils were passed from a 2mm siren and were poured into the test tubes with a soil hopper. To prepare test columns, PVC tubes with a 200 mm diameter were used. For keeping the static level fixed in different depths, we used soft drink bottles put upside-down beside the test tubes. Then, water entered the soil column through a hose inserted at the bottom of the test tube. In this way, the law governing U-shape tubes were used to keep the liquid level in a fixed depth. The schematic shape of these test tubes is shown in Figures 1 and 2.

The static levels were kept constant in depths of 30, 40, and 70 cm from the soil surface. Test treatments included three types of soil texture and three static levels in two repetitions. They were put beside the soil columns. Therefore, the two above tubes were filled with water totally and the amount of evaporated water from their surface was calculated by adding the volume of involved water (Figure 2). To measure the daily evaporation from different soil columns, the amount of evaporated water from the static level of different soils was calculated and the static reduction levels in the bottles were read (the volume of added water for keeping the static level fixed). On the other hand, gypsum block calibration was used for estimating the EF depth in different columns.

Preparation of gypsum blocks

The procedure of building blocks includes the following steps: First, two electrodes were made out of a steel grating net (galvanize iron) 30×150 mm. Then, a double-standard wire No. 50 was opened in one end (2 cm) and about 0.5 cm of its cover was taken with a special tool, and every thread of the wire was connected to the net by a sold machine. Finally, the mold was prepared and electrode wires were placed inside the mold in a way that both electrodes were located inside a gypsum mold cell and passed the embedded holes of the mold. After placing all electrodes, spaces (with the mold) were

Table 1. Physical properties of the soils used in the study

Texture	Sand %	Silt %	Clay %	Apparent bulk density of soil (g/cm^3)	Initial volumetric moisture
Sandy loam	71	19	10	1.68	0.015
Loam	40	47	13	1.38	0.03
Clay loam	35	35	30	1.20	0.04

Fig. 1. Soil columns with static levels.

Fig. 2. Water-filled columns for determining evaporation from the free surface water.

located in both ends of the electron regarding their distances in each gypsum block. It is recommended to check the mold for any hole for the existing gypsum and water mixture. Generally, for preparing one gypsum block, one needs 26 g gypsum and 26 cm^3 water. Therefore, based on the total number of gypsum blocks in every mold, the required gypsum and water were prepared. The deformation of the gypsum blocks is the relationship between the electric resistance of the electrodes and the amount of soil moisture which is done by using a ceramic pot (Figure 3).

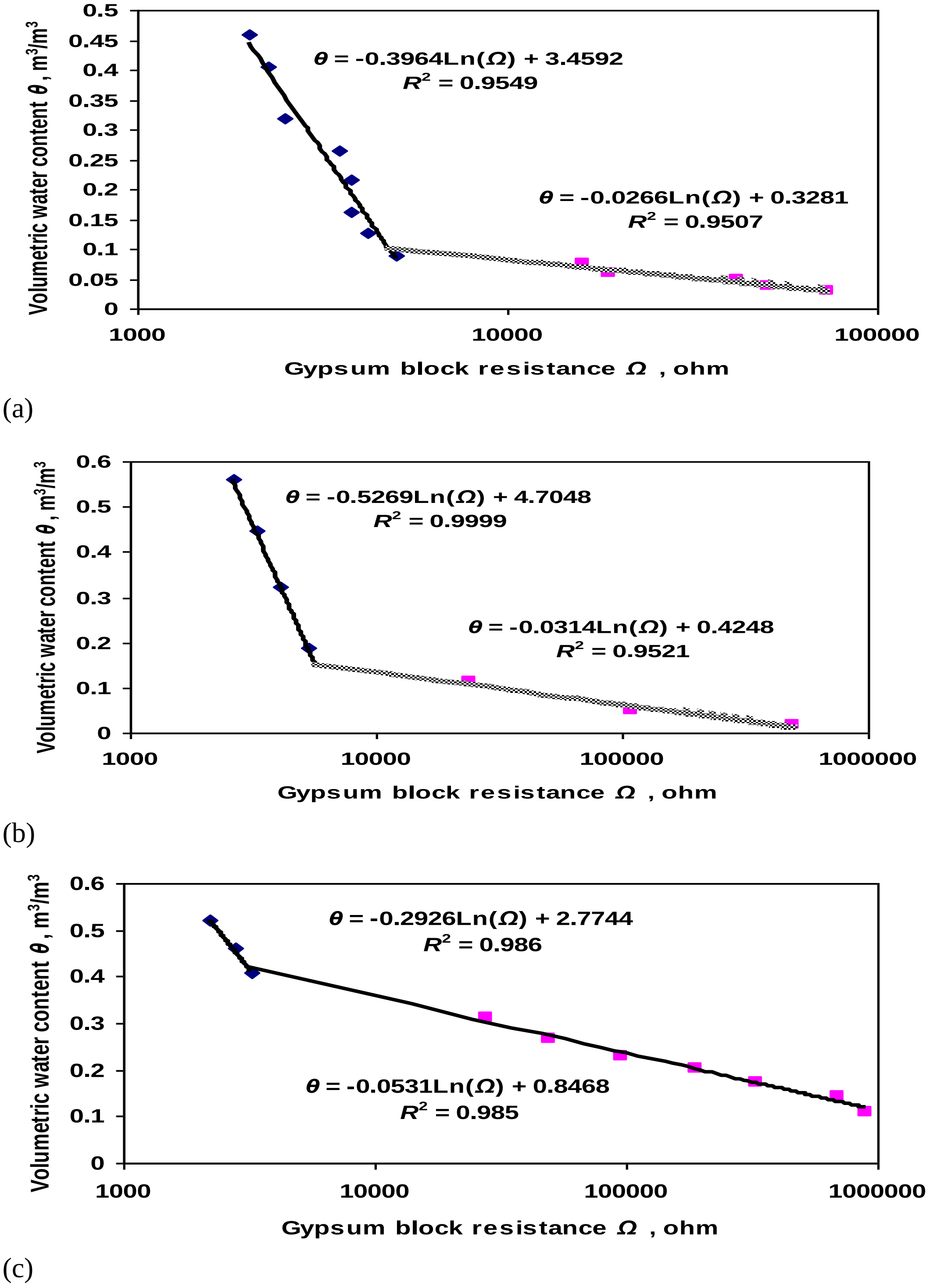

Fig. 3. Gypsum block resistance changes in the moisture content of (a) Sandy loam, (b) loam, and (c) clay loam soils.

Determining the evaporation front depth

In order to determine moisture inside the soil (the EF) up to 28 cm depth from the soil surface, seven holes were considered with a distance of 4 cm. The block wire was passed through them and the blocks were placed in the soil. For facilitating water entrance from the bottles into the soil columns, some soil was put into the test tubes (gravel in 4 cm and 2 cm thick) at the bottom. The soil columns were saturated from downward. During saturation, the tubes were covered with plastic boards to prevent evaporation and to achieve total saturation. After saturation, the caps were taken and readings were done including daily evaporation rate done through adding to the required water volume for fixing the static level, measuring the gypsum block resistance to measure soil moisture for determining the evaporation front depth, evaporation from the free surface of the water as well as daily measurement of maximum and minimum air temperatures. Of course, measuring the gypsum block resistance was performed at first daily (3 days) and then weekly.

Governing equations for simulation

The hypothetical principles of this research are borrowed from the method introduced by (Ripple et al. 1972; Liu et al. 2016). Evaporation from the soil with a clear profile occurs in three stages. In the first stage, evaporation remains unchanged (motionless) i.e., it reduced with a reduction in soil moisture which is due to evaporation of hydraulic conductivity. If the evaporation front of the hydraulic front remains unchanged due to the dryness of the soil surface, it increases (Han and Zhou, 2013). Because of these parameters, the evaporation rate is fixed. During this stage, the evaporation rate equals air evaporation potential. These factors control the evaporation rate. Over years, the soil surface gets drier and the same changes in hydraulic conductivity and hydraulic gradient. The only difference is that because of the reduction in soil moisture which makes changes in the soil moisture front, there is not enough moisture for providing evaporation potential from the soil, and subsequently, the evaporation rate reduces over time. This is the second phase of evaporation. If it continues, reduction of soil moisture will provide conditions in the soil in which water does not move in the soil in a liquid form, so transition occurs through water vapor. In this stage, the controlling factors change soil properties and the evaporation rate from soil and EF remains fixed. This is called the third stage. For calculating EF during these stages, a series of hypotheses are considered:

i. The soil profile is uniform.

ii. Simulation is divided into 2-time stages (Δt) in which time lengths are not identical. During the first stage, time lengths are short and toward the end of this stage, they increase.

iii. During the evaporation process, initial moisture (θ_i) reduces in each time interval, Δt and finally, it limits to θ_e (dry air moisture) which is different for each soil texture.

iv. In the first stage of evaporation, a given depth of the groundwater is lost. Of course, its amount is fixed for every type of soil texture. This stage finishes when the volumetric amount of water in this part drops to θ_e and the depth of the EF equals a given depth.

v. During the second evaporation, the soil profile is not divided into various layers. Considering the minimum amount of allowable soil water in the soil surface (θ_e), any increase in evaporation front depth is calculated in every time span (Δt), and the initial water of soil profile (θ_i) is calculated based on the difference between the intensity of vapor stream (q_v) above the evaporation front and the intensity of liquid water stream (q_l) below it. Dry air moisture in the evaporation front is calculated using the relationships between soil moisture and diffusion

(Rose 1968; Konukcu 1997; Sadeghi et al. 2012).

Evaporation front occurs in three stages

In the first stage of evaporation, the EF depth equals zero and it is just surface evaporation that is calculated based on the modified Penman equation (Penman 1948; Staple 1974; Gowing et al. 2006):

$$E = \frac{R_h \Delta (R_n - G)/\lambda + \gamma E_a}{R_h \Delta + \gamma} \quad (1)$$

In which, E: Evaporation from soil surface (mm/ day), Δ: Slope of vapor pressure curve/temperature (kPa/K), T: temperature (K), R_n: Net radiation (W/m^2), G: Background radiation (W/m^2), λ: Latent heat of vaporization (J/kg), γ: psychrometric constant (kPa/K), E_a: atmospheric evaporating power (mm/day) and defined as $E_a = f(u) \times R_h(e_{sat} - e)$, in which $f(u)$ is the theoretically derived aerodynamic wind function and computed as $f(u) = 0.35(0.5 + 0.54u)$, and R_h: relative moisture of soil water (decimal) which is divided into two parts under salinity conditions, and defined as:

$$R_h = \psi h_0, \psi + h_0 = 3.2 \times 10^6 log R_h \quad (2)$$

where, h_0: osmosis potential (cm), ψ : metric potential (cm), u: the average wind rate (m/s) at 2 m height, e_{sat}: saturation vapor pressure (kPa), e: actual vapor pressure (kPa).

Now, it is time to calculate the intensity of the liquid stream for the first stage. During time length increase, the stream intensity during the first evaporation stage is considered consistent. The equation of a consistent situation of this vertical liquid stream based on the static level is described as follows:

$$q_l = K\left[\frac{d\psi_m}{dz} - 1\right] \quad (3)$$

where,

$$z = \int \frac{d\psi_m}{1+\frac{q_l}{K}} \quad (4)$$

Is derived from the integral equation (Gardner 1958). Here, the relationship between hydraulic conductivity (K) and metric potential (ψ_m), where $K(\psi_m)$ is used as follows:

$$K(\psi_m) = \left[\frac{a}{b+\psi_m^n}\right] \quad (5)$$

where, *a*, *b*, and *n* are constant for each soil texture (Gardner 1958). The analytical method of Eqs. (4 and 5) is used with *b = 0* and *n* = 1, 1.5, 2, 3, and 4 were considered. In every time span of the length, soil profile in the first stage of soil profile loses $\Delta\theta$ water which is calculated based on the following Eq.:

$$\Delta\theta = (E - q_l)\Delta t \quad (6)$$

In the first-time span (Δt_1), soil surface moisture equals to the initial soil moisture (θ_i) and soil surface moisture in the second time span (Δt_2) is calculated as:

$$\theta_{t2} = \left(\theta_i - \frac{\Delta\theta_{t1}}{d}\right) \quad (7)$$

where, *d* is the thickness of the area which has lost moisture in the first length of time interval (Δt_1),. If θ_{t2} is larger than θ_e, the calculation for the successive time intervals is repeated. When surface soil moisture decreased and equaled θ_e, the first stage is completed. At the end of this stage, the EF depth equals z_e = *d*. Since water is wasted in a given depth in the first phase of evaporation, this depth in this simulation is estimated at 2.3 cm. There are two current intensities in the evaporation process of the second stage: Fluid flow intensity below the EF, and vapor flow intensity above the evaporation front. In this condition, the evaporating power of the air is very high whereas the amount of water, evaporated after moving upward in the soil profile and the evaporation front, is limited (Konukcu 1997; Chandra et al. 2001). It is supposed that when EF reached below the witting point, soil moisture has reached to dry air limit. Within the credit limit of equation 3, the maximum liquid flow intensity for the case when z equals to the static surface depth (z_w) is calculated properly as follows:

$$q_{lim} = \frac{A}{z_w^n} \quad (8)$$

where, A = 3.77a for n = 1.5, A = 2.46a for n = 2, A = 1.76a for n = 3, and A =1.52a for n = 4 and a is the constant coefficient.

Equation (8) is used for calculating the maximum intensity of the liquid flow of the static surface in uniformity i.e. when there is no EF or it is very close to the ground. However, when the evaporation front moves downward, the static surface depth of the EF equals $z_w - z_e$ which should substitute z_w in Eq. (8), and modified as follows (Rose 1968; Mualem 1976):

$$q_l = \frac{A}{(z_w - z_e)^n} \quad (9)$$

Equation (9) is used instead of Eq. (8) for calculating the liquid flow intensity below the evaporation front. Here, as mentioned earlier, the amount of soil water θ_e is considered equal with the dry air soil water. For vapor flow, intensity q_v (kg m^{-2} s^{-1}) above the evaporation front following equation is used (Gardner 1958):

$$q_v = \frac{D_v(e_{sat} - e)}{z_e} \quad (10)$$

where, D_v is the diffusion coefficient of water evaporation (m^2 s^{-1}) which is calculated based on the proposed equation by Rose (1968). After the first-time interval, the depth of the EF increases (z_{et2}) and the second time interval is calculated as follows:

$$z_{et2} = d + \Delta z_{et1} \quad (11)$$

$$\Delta z_{et1} = \frac{d\Delta\theta}{(\theta_i - \theta_e)} \quad (12)$$

In Eq. (12), θ_i represents the initial moisture that is obtained using a calibrated gypsum block. In this stage, the soil profile loses water. The amount of the lost water is $\Delta\theta$ that is calculated based on the equation $\Delta\theta = (q_v - q_l)\Delta t$. This process is repeated until steam flow intensity equals fluid flow intensity and reaches a uniform flow. In the third stage (uniform), the liquid flow intensity and vapor flow intensity are identical in depth in which EF in Eqs. (9) and (10) remains unchanged. For calculating the depth of the EF in different soil textures, it is necessary to determine the amounts of θ_e and soil hydraulic properties. In this stage (uniform), the evaporation front remains unchanged, so the liquid flow intensity and vapor flow intensity in equations (9) and (10) are identical in a depth.

RESULTS AND DISCUSSION

To obtain equation parameters (van-Genuchten 1980) soil water retention curve including θ_s, θ_r, α, m, n, and the parameters a, b, and n in Gardner Eq. (1958). Sepaskhah and Yarami (2010) for the three types of soil were used in this study. The results for the sandy loam, loam, and clay loam soils are given in Table 2. The average moisture content of air-dry moisture content at the depths of 0 to 4cm to simulate the evaporation model is presented for the three textures in Table 3. Greenhouse temperature changes were minimum 7 and maximum 43 degrees Celsius, According to the temperatures, the most moisture changes were observed in loamy and sandy loam soils.

The results showed that with increasing depth from the soil surface, the amount of moisture changes decreases with time. In general, the maximum amount of moisture changes is related to 40 mm from the initial soil. (Figure 4). During evaporation, soil volumetric water content after the experiment is initially high and then low. In the sandy loam soil, if the water level is 30 cm initially, the volumetric moisture is 0.27 m^3/m^3 and after 63 days at 0.07

m^3/m^3, if the water level is 40 cm initially, the volumetric moisture is 0.25 m^3/m^3 and after 63 days at $0.06m^3/m^3$, if the water level is 70 cm initially, the volumetric moisture is 0.24 m^3/m^3 and after 63 days at $0.05m^3/m^3$ (Fig. 4a). In the loam soil, the water level is 30cm initially, the volumetric moisture is $0.3m^3/m^3$and after 63 days at 0.13 m^3/m^3 if the water level is 40 cm initially, the volumetric moisture is 0.29 m^3/m^3 and after 63 days at $0.11m^3/m^3$, if the water level is 70 cm initially, the volumetric moisture is 0.26 m^3/m^3 and after 63 days at 0.09 m^3/m^3 (Fig. 4b). In the clay loam soil, if the water level is 30 cm initially, the volumetric moisture is 0.38 $m^3/m^3$and after 63 days at 0.23 m^3/m^3, if the water level 40 cm initially, the volumetric moisture is 0.35 m^3/m^3 and after 63 days at 0.2 m^3/m^3, if the water level 70 cm initially, the volumetric moisture is 0.3 m^3/m^3 and after 63 days at 0.18 m^3/m^3 (Fig. 4c). Changes in a sandy loam soil moisture are initially rapid and changes over time are less(Han and Zhou, 2013; Chari and Afrasiab. 2019; Meng et al. 2019). The effect of the water level in sandy soil at different depths of soil moisture varies. The less depth of the water level, the fewer moisture changes, and the greater depth of the water level, the greater moisture changes. The clay loam soil will slow changes in soil moisture.

Evaporation front depth

The EF depth is very high in sandy loam soils, i.e. lighter the soil texture, the deeper the EF and it is because of low porosity (Nassar and Horton 1989). Likewise, due to the osmosis phenomenon, if the static level gets closer to the ground, the EF depth will decrease. So, in sandy loam soil, in the static level depths of 30, 40, 70 cm, after 77 days the front depths will reach 6.14, 7.85, and 13.86 cm, respectively (Fig. 5a). In loam soil, in the static level depths of 30, 40, 70cm, after 77 days the front depths will reach 5.23, 7.27, and 2.2cm, respectively (Fig. 5b). In clay loamsoil, in the static level depths of 30, 40, 70 cm, after 77 days the front depths will reach 5.4, 7.20, and 10.09 cm, respectively (Fig. 5c).

Table 2. Soil water characteristic curve, equation coefficients, suction, and hydraulic conductivity of unsaturated soils (Gowing et al. 2006)

Ψ_m (θ) parameters (van Genuchten 1980; van Genuchten et al. 1991)						
Soil texture	θ_r ($m^3\ m^{-3}$)	θ_s ($m^3\ m^{-3}$)	α (m^{-1})	***n***	***m***	R^2
Sandy loam	0.040	0.350	0.007	3.297	0.695	0.960
Loam	0.080	0.430	0.040	1.296	0.231	0.970
Clay loam	0.100	0.420	0.006	1.794	0.444	0.990

$K(\Psi_m)$ parameters (Gardner 1958)					
Soil texture	***a*** (m)	***b*** (m)	$a/b = K_s$ ($m\ s^{-1}$)	***n***	R^2
Sandy loam	$4.95x10^{-6}$	$8.27x10^{-4}$	0.00598	4	0.950
Loam	$1.31x10^{-4}$	$6.52x10^{-2}$	0.00209	3	0.960
Clay loam	$4.75x10^{-5}$	$4.35x10^{-1}$	0.00011	2	0.990

Table 3. Average humidity and dry soil moisture at the depth of 0 to 4 cm in different soils

Soil texture	θ_e ($m^3\ m^{-3}$)	**Average depth (cm)**	**Average θ in the transition zone ($m^3\ m^{-3}$)**
Sandy loam	0.05	4	0.06
Loam	0.05	4	0.11
Clay loam	0.17	4	0.19

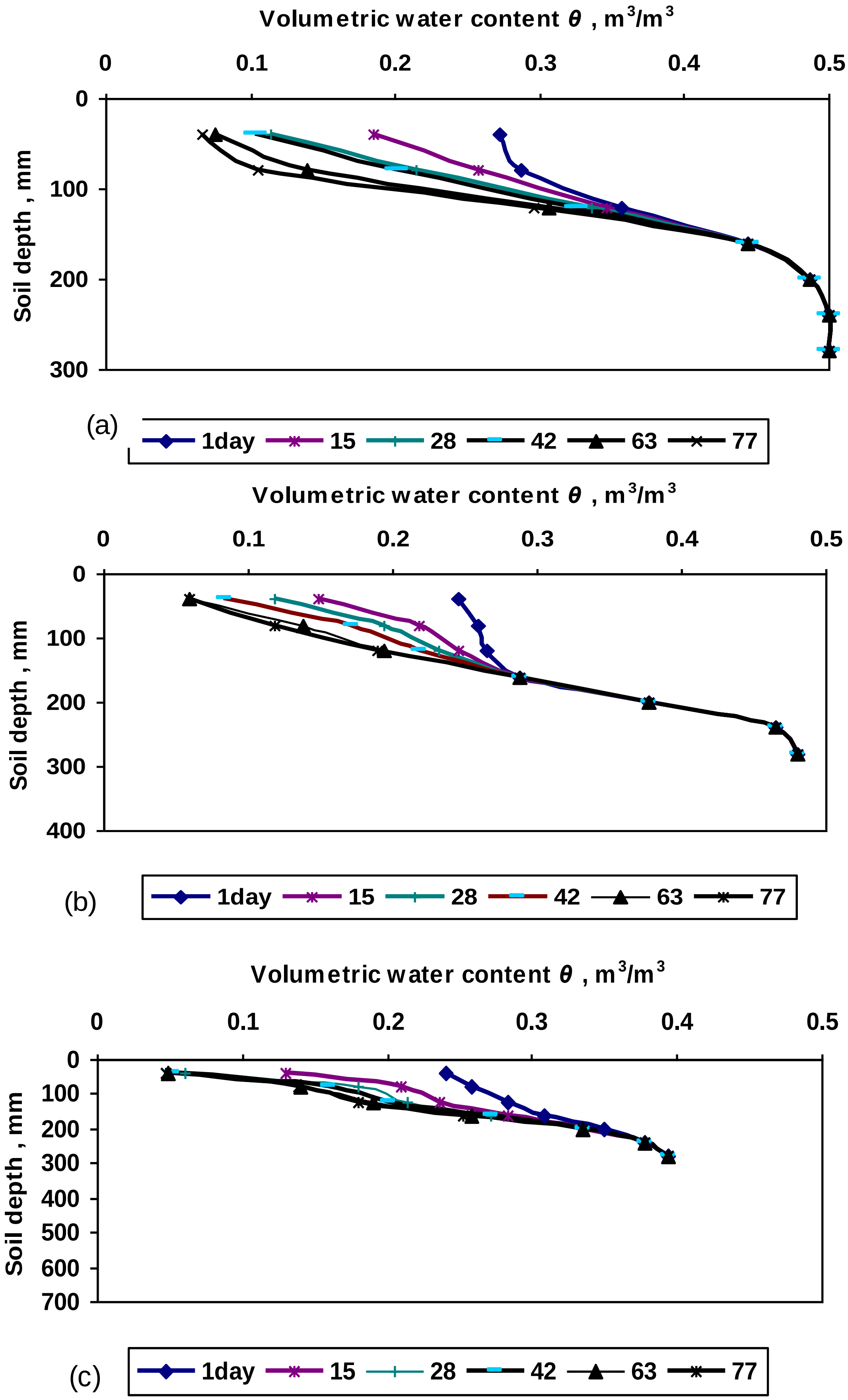

Fig. 4. Evaluation profiles of soil-water content at different times in sandy loam soil (*a* = 30, *b* = 40, *c* = 70cm).

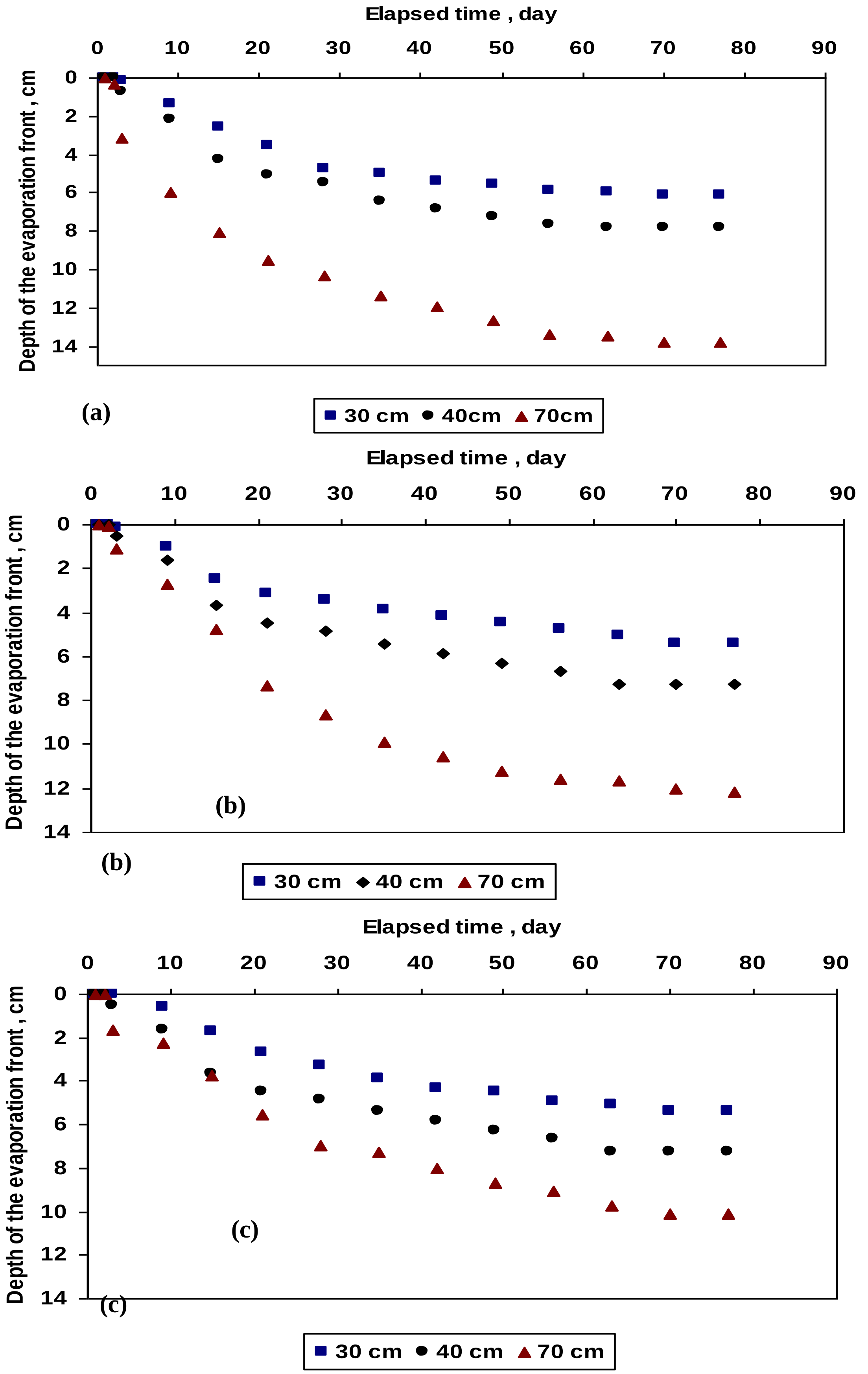

Fig. 5. Changes of EF in (**a**) sandy loam, (**b**) loam, and (**c**) clay loam soils with different depths of static levels.

Evaporation from the soil surface and free water surface

In this experiment, the evaporation rate from the soil surface was daily measured. The evaporation rate equals to the amount of water added to the water reservoir connected to the soil (Figure 6). After a while, the evaporation rate from the soil surface decreases and, it ultimately reaches a fixed rate. On the other hand, the relationship between the evaporation rate from the soil texture and the static level shows that the lighter soil texture, shallower static level causes more evaporation at first, and after some time, this rate drops so that

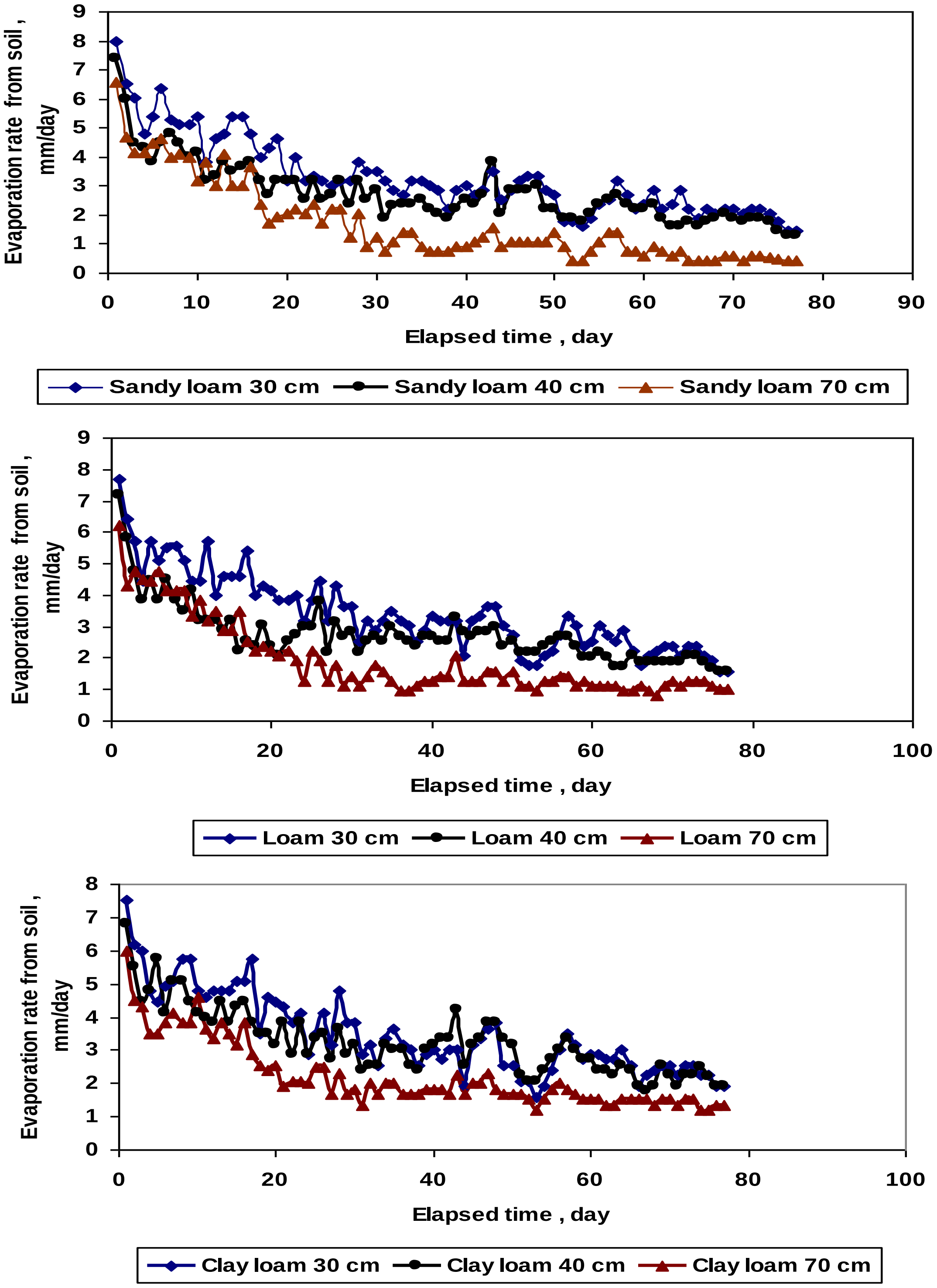

Fig. 6. Evaporation from soil surface with time in sandy loam, loam, and clay loam soils with different depths of static level (30, 40, and 70 cm).

it is less than the heavier texture. Figure 7 shows the evaporation amount from the free surface water and is used to illustrate the length of the first stage of the EF.

Figure 8 shows the ratio of the evaporation intensity from the soil columns in different days to the evaporation rate from the free water in different depths of the static level. When this ratio is equal or close to 1, it shows the length of the first stage of evaporation. As it decreases, the second stage of evaporation starts. It continues until this ratio is fixed. This stability of the ratio shows the third stage of evaporation. In depths of 30, 40, and 70 cm, the duration of the first evaporation stage is 3, 2, and 1 (even less than 1) days. Of course, this ratio is almost the same for different textures as illustrated in Figure 8 (Gowing, 2006; Chari and Afrasiab.2019).

Analysis of the results shows that the evaporation model is more suitable for sandy loam soil. Moreover, some parts of time changes in evaporation intensity are the result of changes in the evaporation power of greenhouse air and the other part is due to changes from one stage to another. The results show that deeper static lengths make the similarity between the measurement results and simulation (Figure. 9 and Figure. 10 a-c) respectively. Comparing the evaluated data of EF with the simulated figures of the evaporation front in textures and diverse static levels using the statistical test showed that a one to one line at a level of 5% is suitable for sandy loam soil. The results of this test show that it is a good model for simulation of the EF of sandy loam soil and static levels of more than 40 and 70 cm (Figure 9). The results are given in Table 4, which highlights that the simulation of the evaporation front in sandy loam soil and the water level is much better than the other.

Figure 11(a-c) to 13(a-c) shows that models provided better simulation for the sandy soil than the others. Heavier soil has a greater difference with the model. The findings of this research are by those of the reported ones (Gowing et al. 2006). For further analysis of the results, the measured and simulated evaporation intensities were compared on a one-to-one line. It showed more uniformity with sandy loam soil. Comparing the measured data of evaporation intensity with the simulated figures of the evaporation intensity in different textures and static levels using the statistical test and a one-to-one line in a level of 5% in sandy loam soil represented that it is much better than the two other soils. The results of this research show that

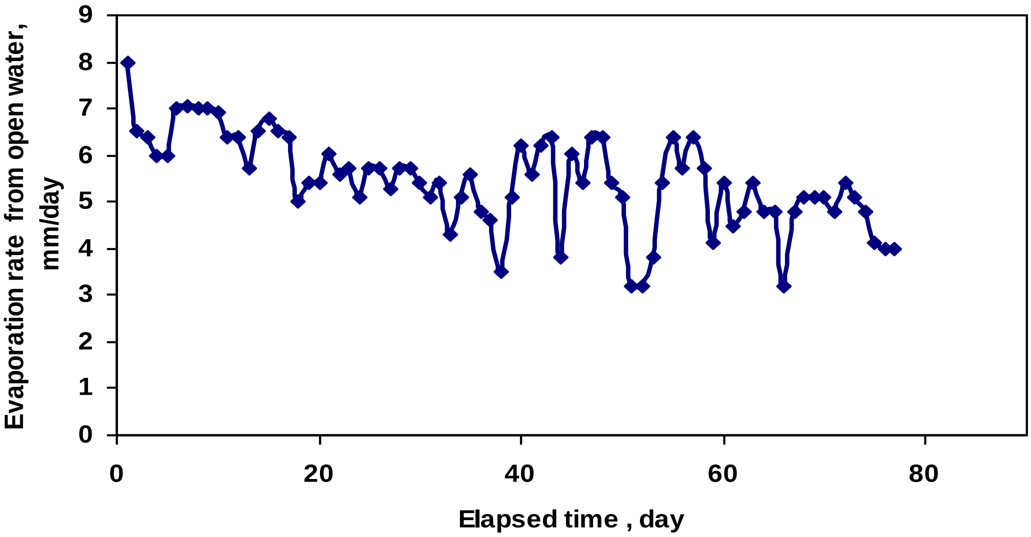

Fig. 7. Average evaporation intensity from free surface water.

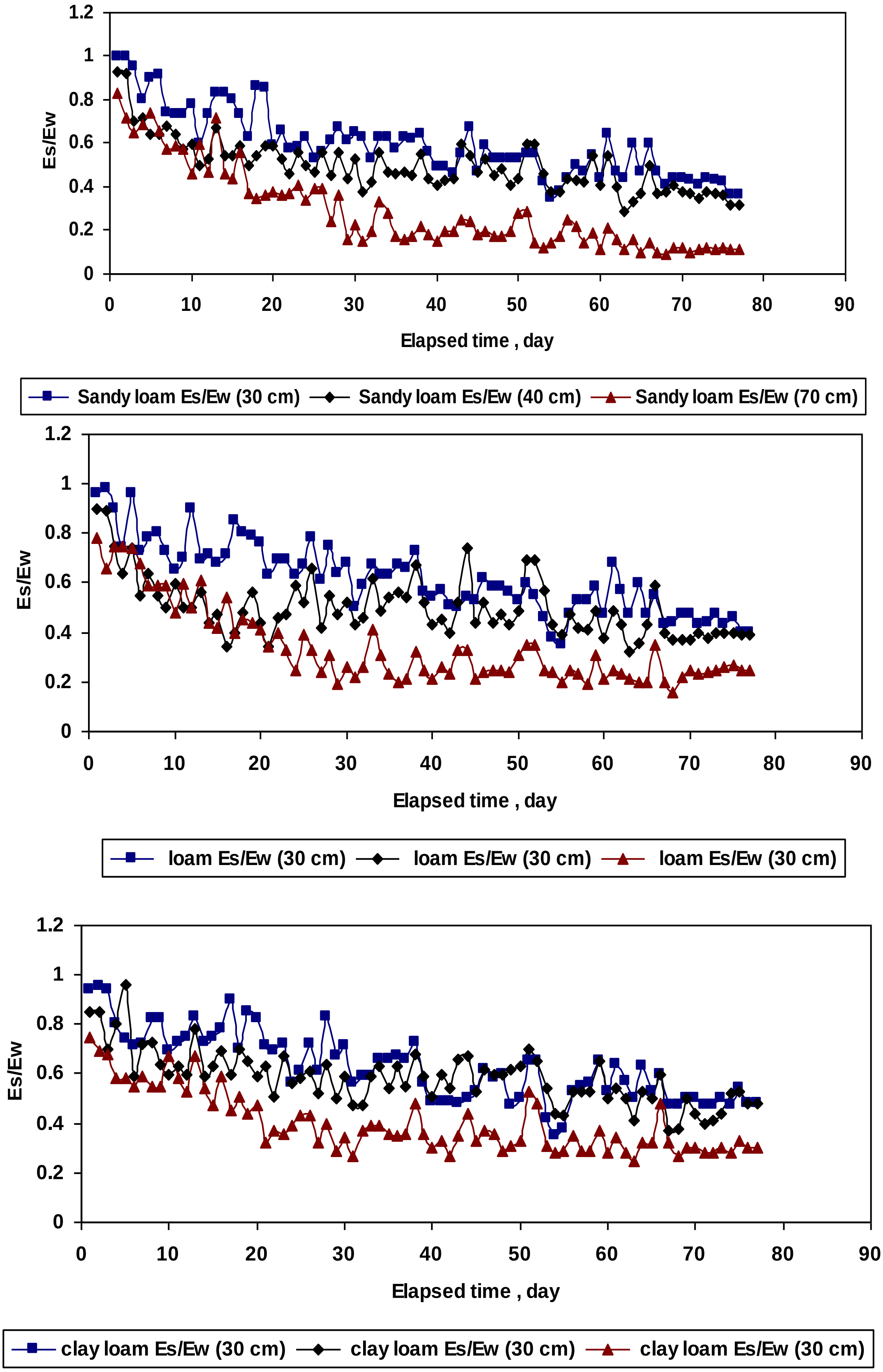

Fig. 8. The ratio of evaporation intensity from sandy loam, loam, and clay loam soils to evaporation from the free surface in different days and soil depths of static level (30, 40, and 70 cm).

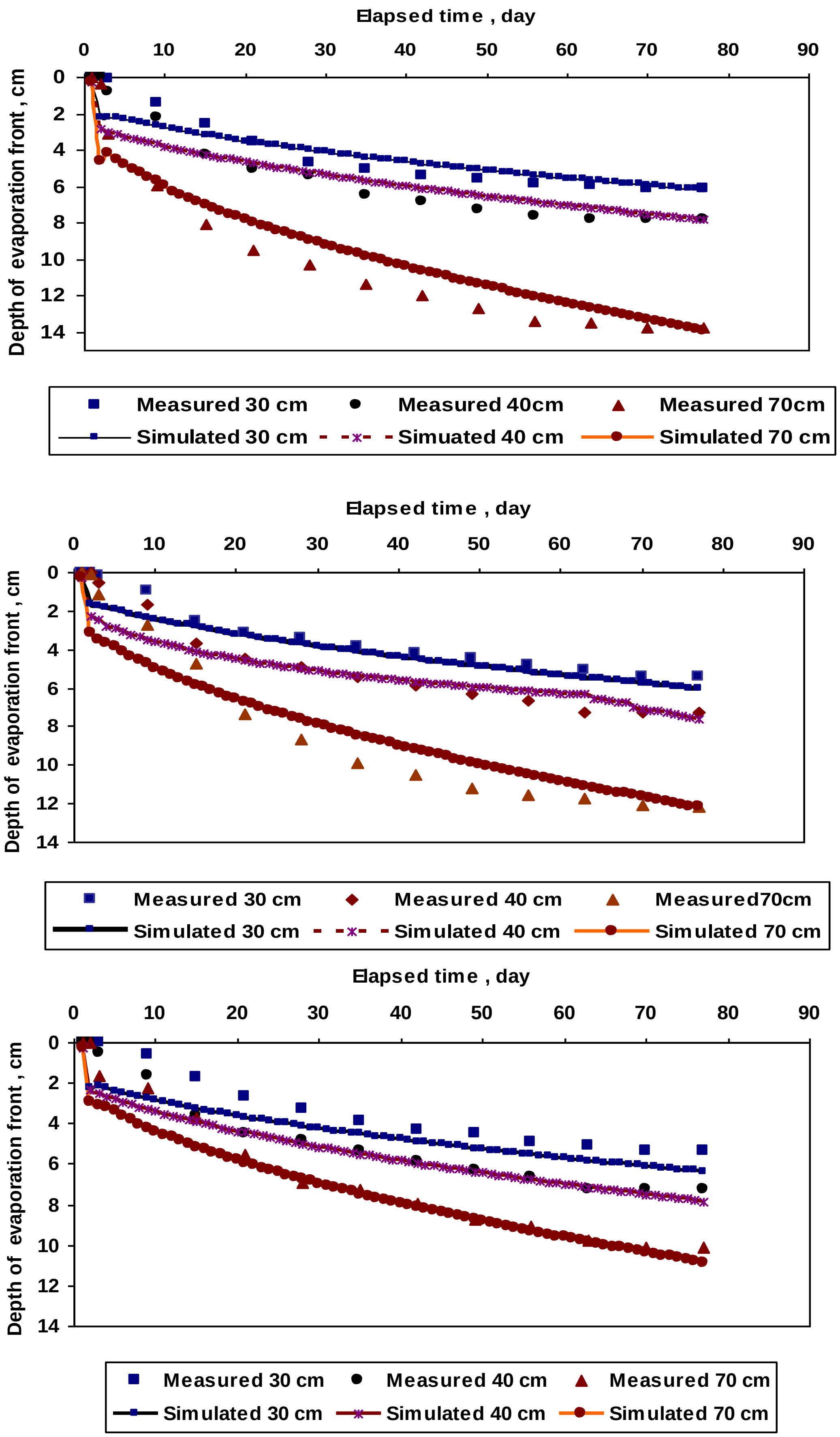

Fig. 9. Simulated and measured changes of evaporation front depth in sandy loam, loam, and clay loam soils in different depths of static level (30, 40, and 70 cm).

regarding simulation of evaporation intensity, this model is more suitable for sandy loam soil and in static level depths over 40 and 70cm, the drawn line slope for sandy loam and loam textures, and between real and simulated data as well had a non-significant relationship with a one-to-one line (Table 5). Regarding Table 5, the ratio of the evaluated evaporation intensity (average in a given period of 77 days) to the simulated mean in sandy loam soil is better and this model is more suitable for sandy soil.

CONCLUSIONS

In this research, a simulating model of uniformity was used to determine the EF depths and the evaporation intensity during a uniform period. This uniformity was obtained at the end of the experiment, not at the beginning. For evaluating the simulation of the model, evaporation depth, and evaporation intensity data, soil columns in the greenhouse of the irrigation part were used. The results showed that the evaporation front depth is more in lighter textures. So that the EF depth in the static levels of 30, 40, and 70 cm in sandy loam soil were 6.14, 7.85, and 13.86 cm after 77 days that is caused by low porosity and long life of the waste in this texture. The heavier soil textures will decrease the EF depth. Moreover, in the case of loam soil, the evaporation front depth in the static levels of 30, 40, and 70 cm in sandy loam soil were 5.23, 7.27, and 12.2 cm after 77 days and in the same period, for clay loam soil, it reaches 5.4, 7.2, and 10.9 cm. The deeper the static level, the deeper the evaporation front. Simulation of the evaporation front depth for sandy soil comparing with loam and clay loam textures has more harmony with the measured depth of the evaporation front. Moreover, the results show that in clay loam soil, the mean of the measured evaporation intensity in more than the other textures, especially in static level depths of 40cm or more whereas is the static levels of 30, 40, and 70cm, the average evaporation intensity is 3.47, 3.21, and 2.22 ml/day. On the same levels, the average evaporation intensity for loam soil is 3.41, 2.73, and 1.94 mL/day and for sandy loam soil, they are 3.31, 2.74, and 1.7 mL/day, respectively. Estimated results showed that the evaporation model for sandy loam soil was better than the other kinds of soil. In fact, the heavier the soil texture, the less similarity between the model and the evaluated character. These obtained results are in accordance with those of the reported ones (Gowing et al. 2006). The most limitation of the uniformity model of air evaporation during different stages is evaporation. During the first stage of evaporation, water is wasted in a given depth which in-simulated

Table 4. Comparison of measured data with simulated values by evaporation fronts in various textures and analyzed with the water level to a one-to-one line of 5%

Soil texture	Water level depth (cm)	Slopes	Intercepts
Sandy loam	30	Non-significant	Non-significant
	40	Non-significant	Significant
	70	Non-significant	Non-significant
Loam	30	Significant	Non-significant
	40	Significant	Significant
	70	Non-significant	Significant
Clay loam	30	Significant	Non-significant
	40	Significant	Non-significant
	70	Significant	Non-significant

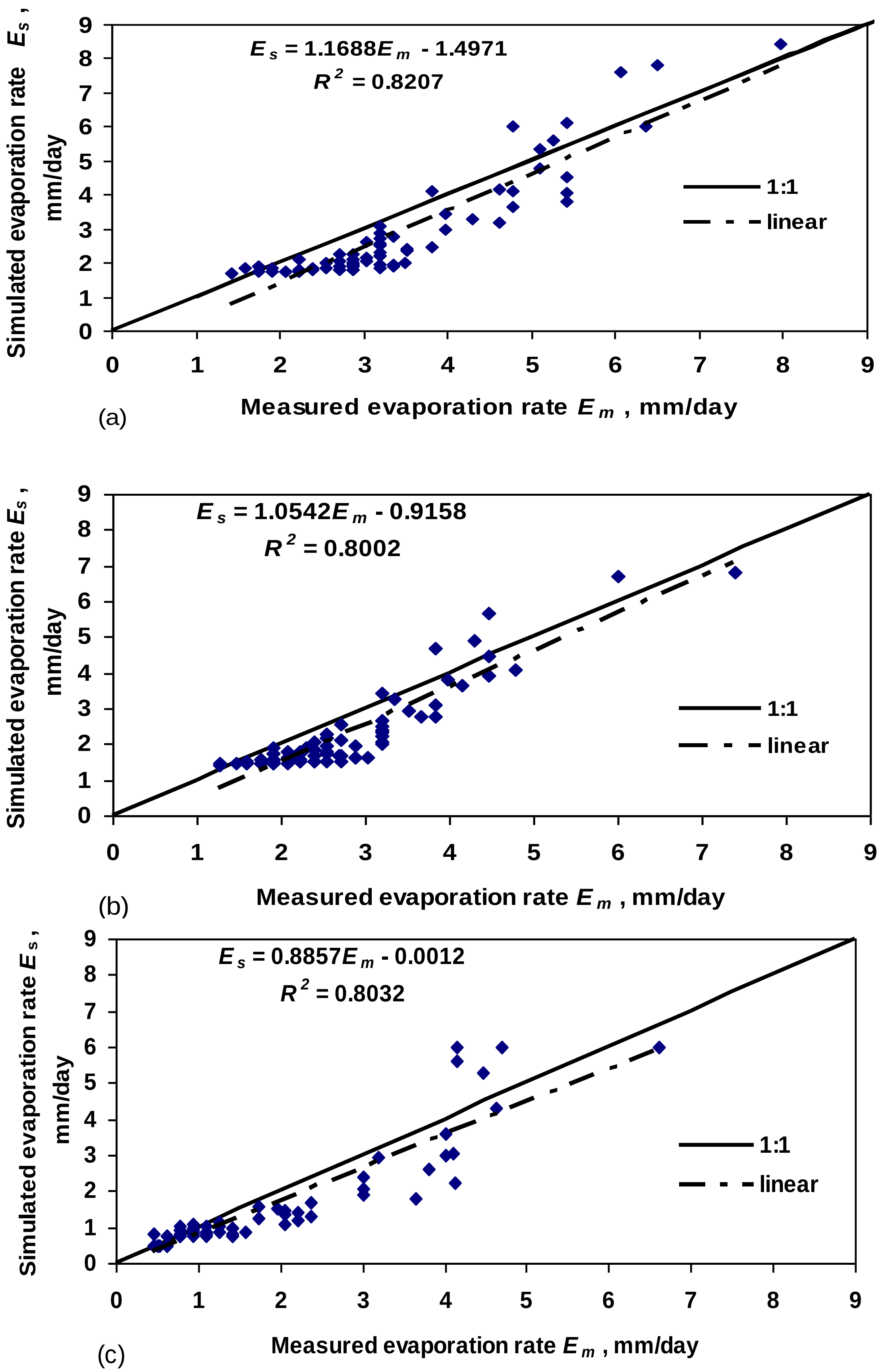

Fig. 10. Comparison between the measured and simulation EFD for three texture (a) sandy loam, (**b**) loam, and (c) clay loam soils in 30 cm water level.

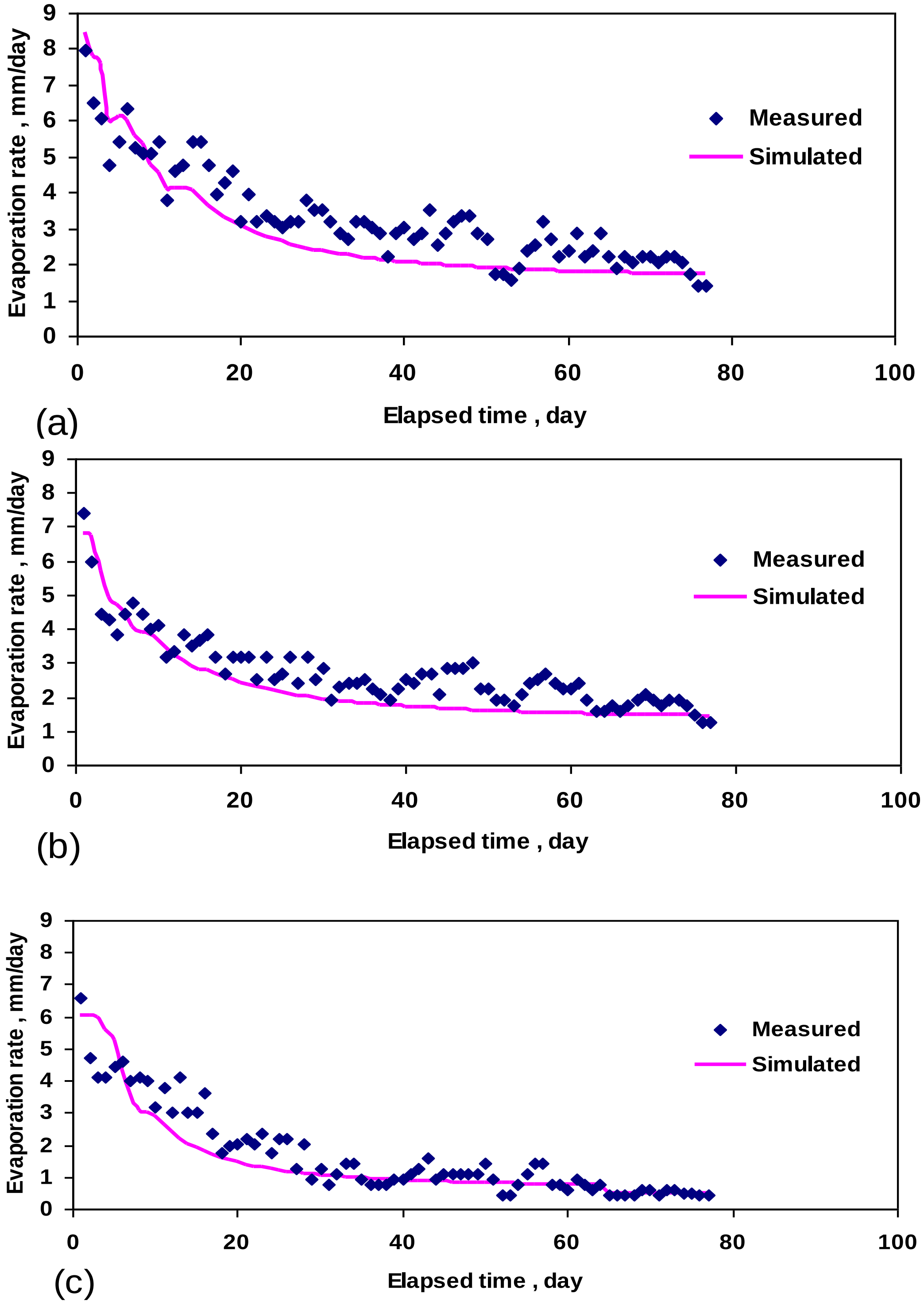

Fig. 11. Simulated and measured changes of evaporation intensity with time for sandy loam soil in (**a**) 30 cm, (**b**) 40 cm, and (**c**) 70 cm static levels.

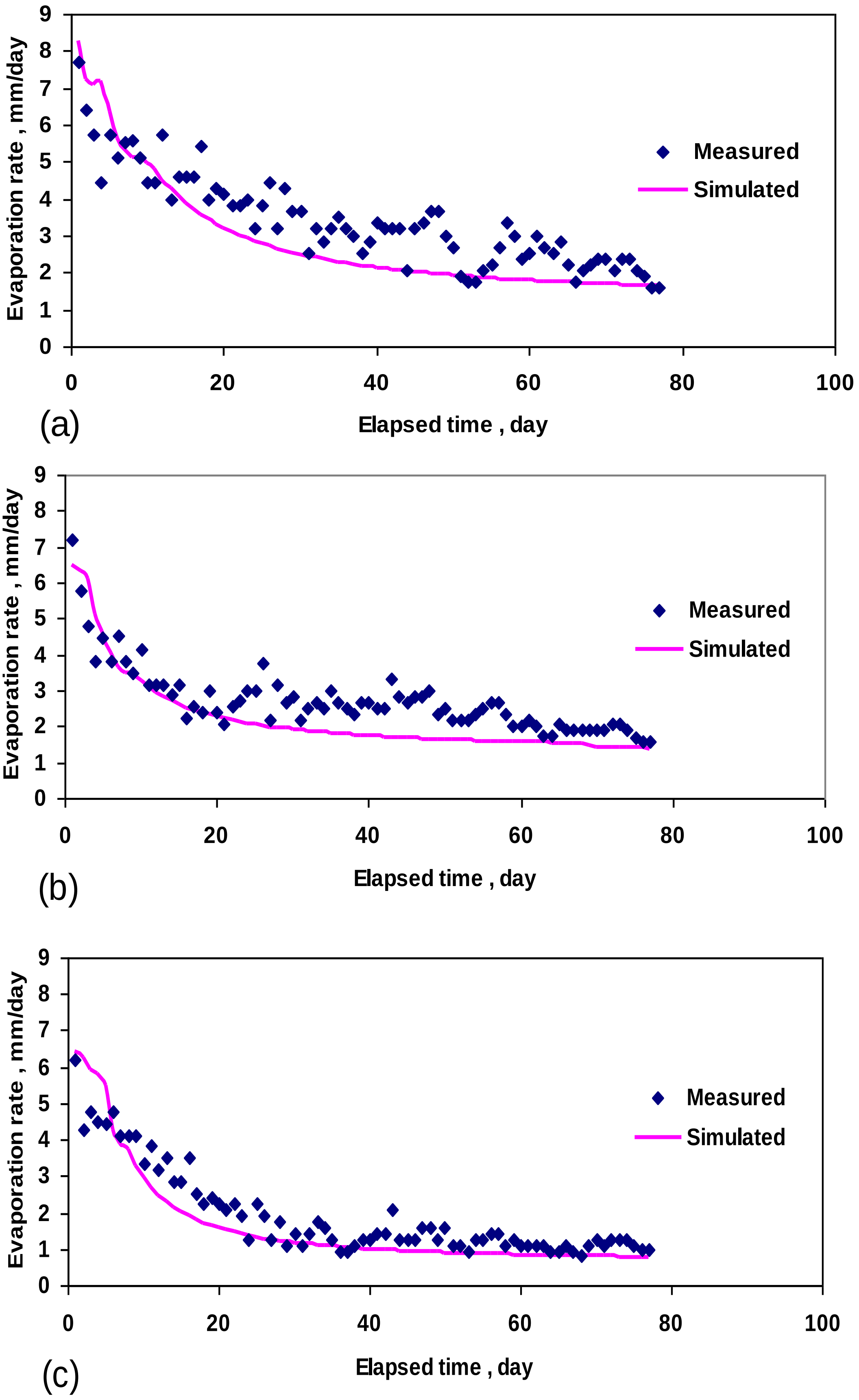

Fig. 12. Simulated and measured changes of evaporation intensity with time for loam soil in (**a**) 30 cm, (**b**) 40 cm, and (**c**) 70 cm static levels.

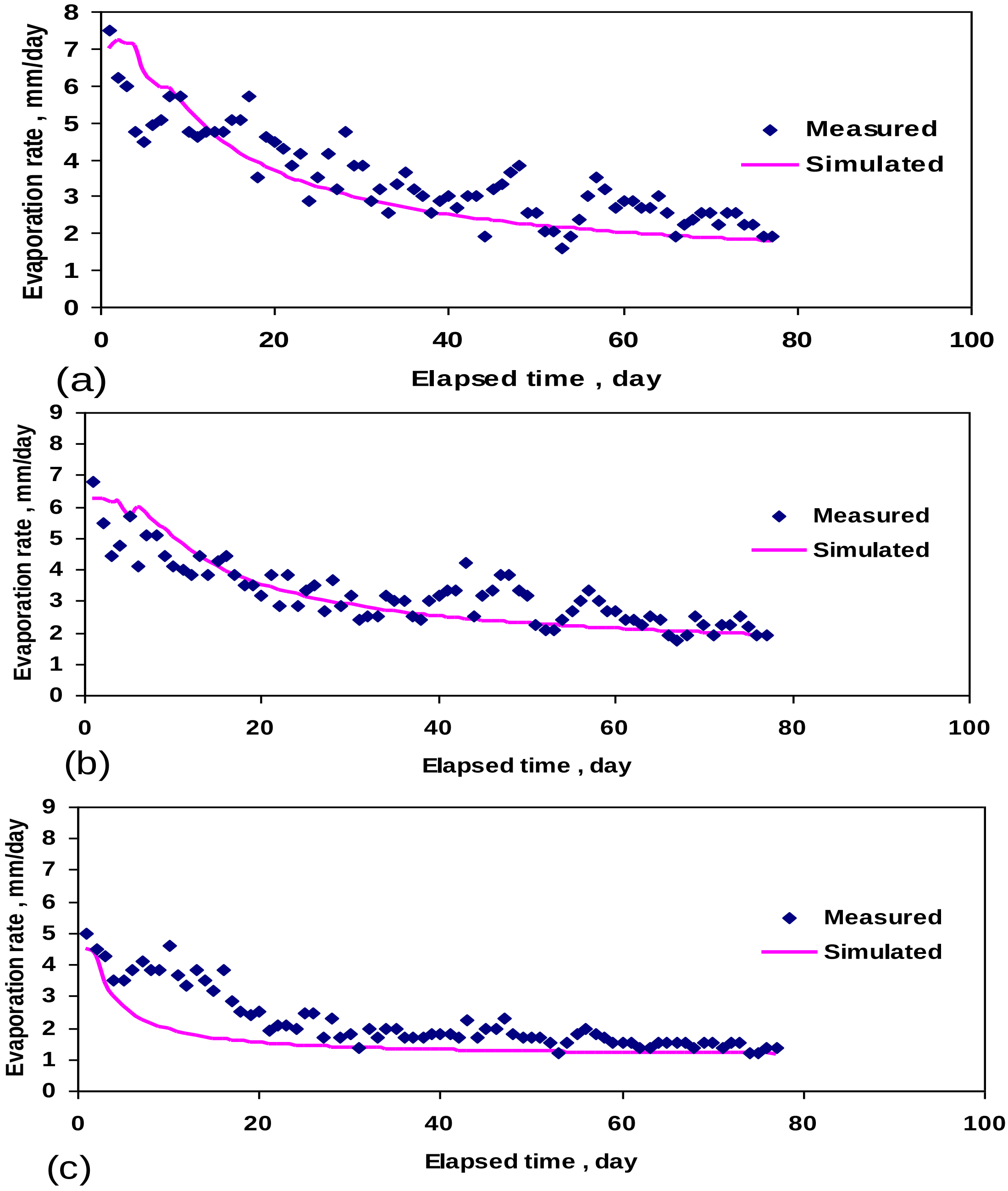

Fig. 13. Simulated and measured changes of evaporation intensity with time for clay loam soil in (**a**) 30 cm, (**b**) 40 cm, and (**c**) 70 cm static levels

Table 5. Comparison of the measured evaporation intensity (E_m) and the simulated one (E_s) in a non- consistent state (Gowing et al. 2006)

Soil texture	Water level depth (cm)	E_s using Eq. (8) (mm/day)	E_m (mm/day)	E_s/ E_m
Sandy loam	30	1.2	1.4	0.85
	40	1.1	1.3	0.90
	70	0.7	1.0	0.76
Loam	30	1.0	1.6	0.62
	40	0.7	1.5	0.46
	70	0.5	1.1	0.43
Clay loam	30	0.9	1.9	0.50
	40	1.1	1.9	0.59
	70	0.8	1.4	0.58

situation is 2.3 cm and of course, its results are following the obtained ones. The simulating model of evaporation is based on isothermal conditions. This is another mal theory to simplifying the simulation model is considered. This simplification of the acceptable results is used in simulating the EF movements and the evaporation rate. Because of the high-temperature gradient in the soil surface in dry and semi-dry areas, we did not achieve any accurate results so some of these time changes in the evaporation intensity originate from the changes in the evaporation power of greenhouse air, and the remaining parts are related to changes in the evaporation conditions from one stage to another.

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