Effect of Soil Water Content and Salinity on Daily Evaporation from Soil Column

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Abstract: The paper was presented in order to demonstrate the performance of the maximum surface temperature model (MSTM) developed for estimating soil evaporation based on surface energy balance and the periodic various in soil surface temperature. In this study, to minimize the influence of meteorological factors on evaporation, a relative evaporation (*RE*) was used to demonstrate the change in the estimated evaporation from non-saline and saline soils with differ initial soil water content. It was a positive correlation between the ***RE*** and soil water content, which indicated that the MSTM may be affected by the soil water. And the evaporation from saline soil was less than that from non-saline soil, which was attributed to the effect of salt accumulating on soil surface reducing the evaporation. At the same time, the MSTM can also show the stage of soil evaporation during entire observation. Therefore, it is indicated that the MSTM may be used to predict the daily evaporation by using only soil surface temperature. [Journal of American Science 2010; 6(8):576-580]. (ISSN: 1545-1003).

Keywords: Non-saline and saline soils; Soil surface temperature; Soil evaporation; Soil water content

1. Introduction

In order to maintain the sustainable development of irrigated agriculture in arid region, an accurate knowledge of water loss from soil is necessary. In general, the main routes of soil water loss are evaporation and transpiration. The soil evaporation and crop transpiration are often considered together as the evapotranspiration (ET), yet each part is variable portion to water balance in farmland scale. In many parts of the world the available water resources are presently being trapped close to the limit, so that an accurate knowledge of the consumptive use through evaporation is indispensable (Brutsaert, 1982).

In arid irrigated regions, such as an agricultural area of Hetao, which is located in a cold and arid region in China, there is a contradiction of water supply and demand owing to the rapid development of regional economy and shortage of water resources in recent years. And most of saline lands are distributed in the district. The saline soils are considerably resulted from the irrigated water containing salinity and the high evaporation in the district. However, the evaporation not only makes water loss but also may induce secondary salinization in the district. Also, plant growth is considered as a function of the total soil moisture stress. These are the sum of the soil moisture tension and the osmotic pressure of the soil solution (U.S. Salinity Laboratory Staff, 1954).Thus, such as regions will have to face an important challenge for increasing food production in order to realize food security for a growing population while optimizing the use of limited water resources (FAO, 1994) and controlling the salinization of soil.

To avoid the salt accumulation in soil, the leaching irrigation (locally named autumn irrigation) needs to be implemented at October every year in the district. Now, the district is facing the water resources shortage and the soil salinization problems. Some studies (Shi, H. B., Akae, T., et al. 2002; Akae, T., et al. 2004, 2008) have concerned with these problems for sustainable irrigated agriculture in the district.

Soil evaporation is affected by most of factors in natural environment, which includes mainly two aspects: climate aspect (net radiation, wind speed, air temperature, etc) and soil aspect (soil types, soil water content and temperature, hydrological properties, soil salinity, etc). The processing of soil evaporation is often divided into two or three stages based on the evaporative capacity of atmosphere and available water in soil for evaporation (Lei, et al. 1988; Jury, W. A., Horton, R. 2004). For soil temperature aspects to evaluate of soil evaporation, some studies (Ben-Asher, 1983; Evett, 1994; Qiu, 1999) have been addressed. To the larger scale, using the soil temperature to estimate of evaporation may be concerned greatly in the future due to the available temperature data from satellite image. In general, the soil water is considered as a major of factor affecting evaporation directly. In fact, the surface temperature may be considered as the indirect factor on soil evaporation. Thus, the aim of this study is carried out to show the performance of the developed model for estimating evaporation only with surface temperature.

2. Theoretical background

Under neglecting the energy stored in soil, the soil surface energy balance can be expressed as

$$R_n = H + G + \lambda E \quad (1)$$

Soil energy balance for each soil column can be written based on the equation (1) as follows:

Control soil column: $$R_{no} = H_o + G_o \quad (2)$$

Wet soil column: $$R_{nd} = H_d + G_d + \lambda E_d \quad (3)$$

where, R_n, H, G and λE are the flux density of net radiation, sensible heat, soil heat and latent heat. The subscripts o and d refer to the control and the wet soil columns, respectively. The λ is the latent heat of vaporization (2.45 MJkg-1).

The net radiation term (Brutsaert, 1982) is also given by:

Control soil column: $$R_{no} = R_s(1-\alpha_{so}) + R_{ld} - R_{luo} \quad (4)$$

Wet soil column: $$R_{nd} = R_s(1-\alpha_{sd}) + R_{ld} - R_{lud} \quad (5)$$

where R_s is global short-wave radiation, αis albedo of soil surface, R_{ld} is the downward long-wave radiation, R_{lu} is the upward long-wave radiation.

The long-wave radiation can be written by:

$$R_l = \varepsilon_a \sigma T_a^4 \text{ (or } \varepsilon_s \sigma T_s^4\text{)} \quad (6)$$

where ε_a is the emissivity of air, ε_s is the emissivity of soil surface, σ is the Stefan-Boltzmann constant (5.67×10-8 W m-2K-4), T_a and T_s are air and soil surface temperature, respectively.

Sensible heat flux in energy balance can be written as follows:

Control soil column: $$H_o = \rho C_p c_h (T_o - T_a) \quad (7)$$

Wet soil column: $$H_d = \rho C_p c_h (T_d - T_a) \quad (8)$$

where ρ is air density, cp is specific heat of air at constant pressure, T_o, T_d and T_a refer to surface temperature for control and wet soil column and air temperature (Kelvin). The c_h is the exchange coefficient for sensible heat flux (m/s).

Soil surface temperature is supposed as the change in sine function in equation (9):

$$T(0,t) = 0.5(T_{\max} + T_{\min}) + 0.5(T_{\max} - T_{\min})\sin(\omega t - \theta) \quad (9)$$

here $T_{\max}$ and $T_{\min}$ are the maximum and minimum surface temperature of soil column.

Soil evaporation was estimated based on a maximum surface temperature model (MSTM) in equation (10), the detail procedures of developed model is not presented here:

$$E_d = 7.2(\rho C_p c_h + 4\varepsilon\sigma T_{\min}^3)\Delta T_{\max}/\lambda \quad (10)$$

where E_d is soil evaporation estimated (mm/d), $T_{\min}$ is the minimum surface temperature for both of control and wet soil columns (from observed temperature, the $T_{\min}$ is almost equal for the control and wet soil columns), in this study, the c_h given 69.45 m/h, $T_{\min}$ taken 281.3 K. $\triangle T_{\max}$ is the difference in maximum surface temperature of control and wet soil columns.

3. Material and Methods

The experiment was conducted in the Water Cycle Facility (34˚41′ N, 133˚55′ E, and 4 m elevation), Okayama University Japan. The experiment site is located in the 21 m distance from south of the weather station. A loamy soil was collected from Hetao Irrigation District, China. The undisturbed soil were sampled by excavation in field, and the disturbed soil materials were also collected and then brought to laboratory for air dry and pass a 2 mm sieve. The loamy soil was divided into two parts based on the level of salinity ($EC_{1:5}$) in 1:5 air-dry soil/distilled water extracts, one was non-saline loam (LN, $EC_{1:5}$=0.6mS/cm); another was a saline loam (LS, $EC_{1:5}$=4.9mS/cm). The air-dry soil was moistened to desired initial gravimetric soil water content by adding distilled water. The initial soil water content was 30% for higher moisture (LNW, LSW), 12% for lower moisture (LND, LSD), and next to 0% (CT) for control treatments, respectively. These soil materials were packed into plastic buckets (15 cm length, 9.8 cm top inside diameter and 9.2 cm basal inside diameter) with the wall thickness of 0.2 cm in the bulk density of 1.46g/cm^3 (non-saline loam) and 1.48g/cm^3 (saline loam), respectively. The plastic buckets were packed in 2.5 cm increments for uniform distribution along the whole soil column length. At the same time, the soil temperature cables were carefully embedded at 12.5 cm, 10 cm, 7.5 cm, 5 cm, and 2.5 cm soil depth and surface layer to measure the soil profile temperature and then temperature recorders (TR-52S, T&D Co.) were packed together in a plastic box. These plastic buckets were called soil columns or the mirco-lysimeter (ML).

The surface temperature was determined by using infrared thermometry (Raynger ST, Raytek, Co.). The 5 points were randomly taken on each surface soil column. The surface temperatures were measured and recorded the average of five readings as the surface temperature.

Soil columns were put into cylinders (15.5 cm length, 10-cm diameter) with 0.5 cm thickness of foam sheet for insolating heat conduction. The tops of the soil columns and cylinders were maintained the same level with field surface. Weigh of soil columns were weighed daily at about 9:00 by using a precision of 0.1g with electronic balance (ELB 3000, Shimadzu Co.) Soil water content was calculated based on water balance with the daily weigh of soil column. Soil water retention curves (pF-moisture curve) of saline and non-saline loam were measured by pressure plate (DIK-3400, Daiki Rika Kogyo Co., LTD)

4. Results and discussions

The change in soil water content in each soil column was decreased with time under theoretical considerations. Thus, the soil water content in each soil column based on water balance is presented in Figure 1.

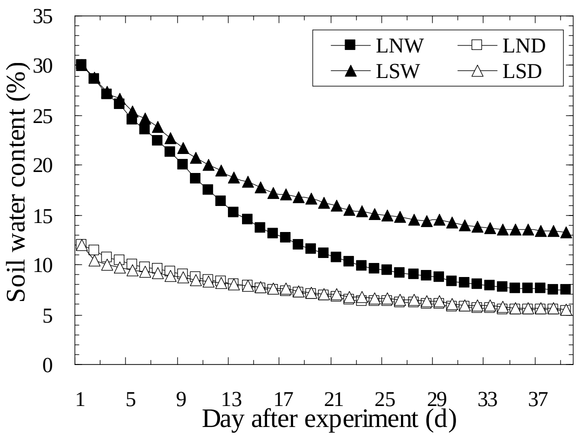

Figure 1. Change in Soil Water Content during Observation

Figure 1 gives that the change in soil water content under daily evaporation conditions from the saline and non-saline soils with different initial soil water levels. The curves in Figure 1 shows that the soil water content rapid decreases with time under high initial water contents at the begin periods of experiment, when the water contents reached to certain values, the change trend becomes smaller and reaches to steady state at the end of experiment, these values were about 10% for LNW, 15% for LSW; at low water content conditions, the decrease in soil water content is smaller for LND and LSD. The differences in soil water content between LNW and LND, LSW and LSD, the main reasons were attributed to different initial water content. The difference in soil water content between LNW and LSW was owed to the impact of salinity on soil water movement.

In general, the range of pF value from1.5 to 4.2 is often considered available water for plants (Yahata, T., et al. 1983). The available water may influence the soil evaporation. In order to demonstrate the event, we made the pF-moisture curves of studied soils, which are presented in Figure 2.

Figure 2 indicates that the water content is slightly larger for saline soil than non-saline soil during the range of the available water, which results to the reducing in soil evaporation from saline soil. It was also indicated that the water hold capacity in saline soil was larger than non-saline soil, which may affect the soil evaporation. These are consistent with observation of the experiment. The water hold capacity of soil is demonstrated by soil water retention curves in next section.

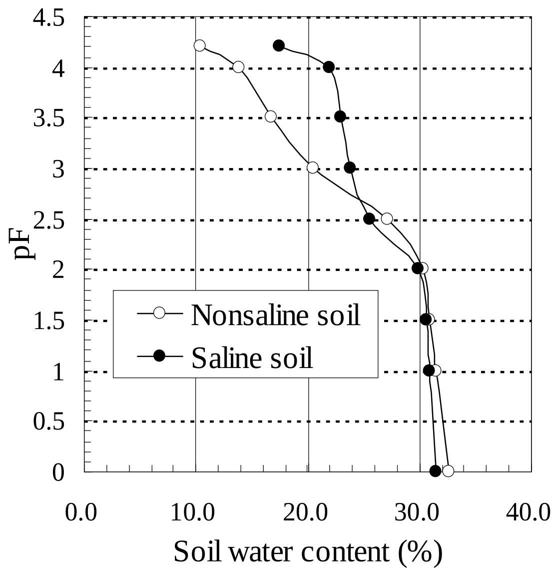

Figure 2. Soil Water Retention Curves for Non-saline and Saline Soils

In order to quantify water content effects on evaporation, we used the Van Genutchen's equation (Van Genutchen, M. T., 1980):

$$\theta = \theta_r + \frac{(\theta_s - \theta_r)}{\left[1+(\alpha h)^n\right]^m} \tag{11}$$

where θ_r and θ_s are residual water content and saturated water content, h is pressure head, α, n and m are curve-fitting parameters. The parameters were fitted by using RETC (Van Genutchen, M. T., 1991).

Due to the same soil type for nonsaline and saline soil, the fitting parameters are similar, which are listed in Table 1.

Table 1. The Results of Fitting Soil Water Retention Curves

	θ r (kg kg^{-1})	θ s (kg kg^{-1})	α (cm^{-1})	*n*	*m*#
Loam	0.078	0.43	0.036	1.56	0.35

m =1-1/n

In order to minimize the influence of meteorological factors on evaporation, we used the relative evaporation (*RE*) to demonstrate the change in the estimated evaporation under different soil water content. It is shown in Figure 3.

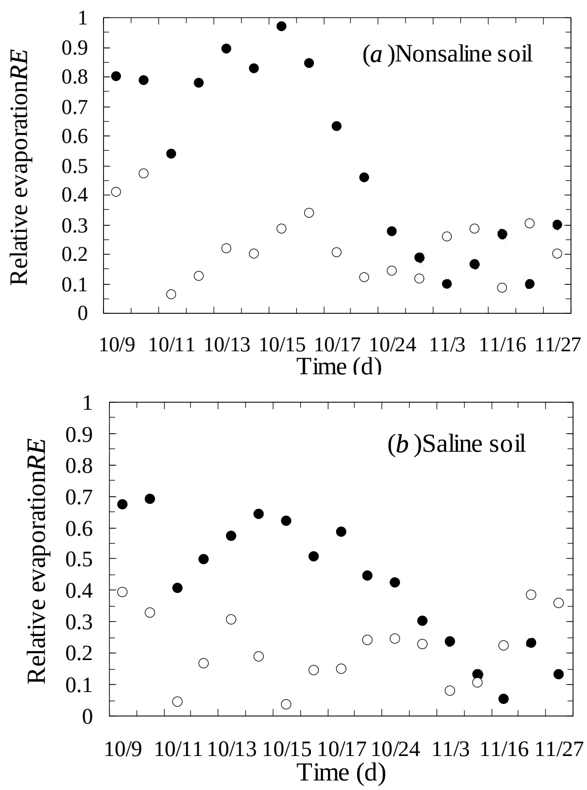

Figure 3. Change in Relative Evaporation under Different Soil Water Content with Non-saline (*a*) and Saline (*b*)

Figure 3 shows the change in ***RE*** estimated from the MSTM under different initial soil water content for non-saline and saline soil. The closed and open circles in Fig.3 refer to the evaporation under high initial soil water (30%, pF=1.8) and low soil water content (12%, pF=4.2) conditions, respectively. The difference in evaporation rate was attributed to the effect of salinity under the same water content and meteorological conditions. In Figure 3 can be seen the processing of evaporation. The dashed made off the different stage of soil evaporation based on change performance of estimated *RE*. At the first one week period of experiment, the evaporation of soil was in the first stage, this period the soil evaporation is major affected by the meteorological factors. After then, when the evaporation come into the second stage (falling stage), this period the soil evaporation is mainly controlled by soil-self water content. It is indicated that the developed model can determine the evaporation stages: the first stage of evaporation was during the first 7 day period of experiment (in Figure 3*a*) corresponding the soil water content was more than 22.5% (pF=2.0) (in Figure1), the second stage was from 7th to13th day after experiment (in Figure 3*a*) corresponding soil water content was from 22.5% to 10.3% (pF from 2.0 to 2.8)(in Figure 1) for non-saline soil; the first stage was the first 6-day period of experiment (in Figure 3*b*) corresponding soil water content was more than 25.4% (pF=1.9) (in Figure 1), the second stage of evaporation was from 6th to 14th day after experiment (in Figure 3*b*) corresponding soil water content was from 25.4to 15.5% (pF from 1.9 to 2.3) for saline soil.

For further demonstrate the developed model can described the effect of soil water content on evaporation, the relationships of the relative evaporation and soil water content are presented in Figure 4.

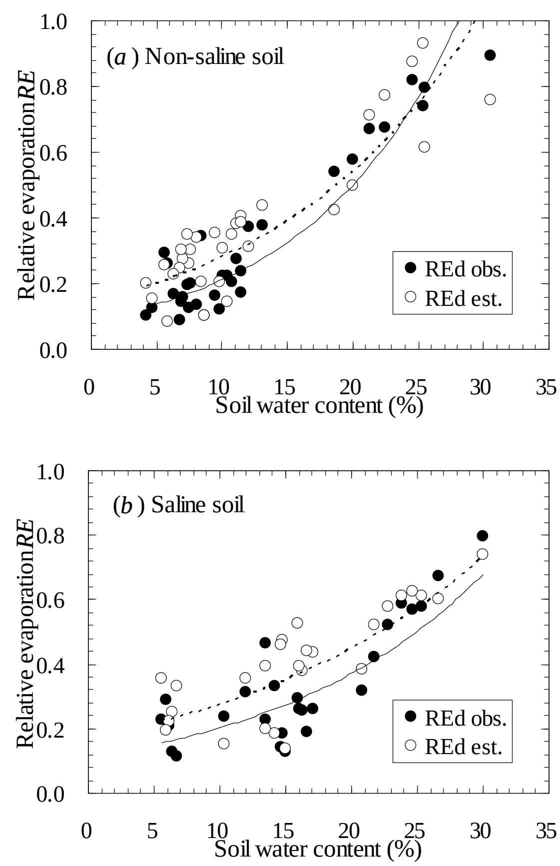

Figure 4. The Effect of Soil Water Content on Relative Evaporation under Nonsaline Soil (*a*) and Saline Soil (*b*)

Figure 4 shows the agreement in the observed and estimated ***RE*** along with the change in soil water content. The ***RE*** is decreasing with the reducing in soil water content, which means the evaporation rate decreasing with the reducing soil water content. At the higher soil water content, the ***RE*** estimated was close to the ***RE*** observed. At lower soil water content, however, the ***RE*** estimated overestimated the ***RE*** observed. The reasons may be that the c_h was used for the all of soil water range and the small evaporation itself at lower soil water content.

Especially, the efficiency of developed model was greater the non-saline soil than the saline soil. Therefore, the developed MSTM can describe the effect of soil water content on evaporation and be hopeful to be used to large scale for estimating soil evaporation only using surface temperature.

5. Conclusion

Some results obtained from this study concluded that are 1) the evaporation from salt-affected soil was less than that of non-saline soil under the same climate condition, the main reasons may be due to the effect salt accumulating on soil surface reducing the soil evaporation, 2) the developed model (MSTM) also can reveal the stage of soil evaporation and, 3) the simple model developed can describe the effect of soil water content on evaporation.

The simple MSTM is hopeful to be used to estimate soil evaporation for large scale only by using surface temperature.

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