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The Application of LEACHW Sub-Model to Estimate Evapotranspiration

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ABSTRACT

An experiment on soil without plants and soil under maize cultivation was performed to evaluate water movement in soil under water stress conditions. In this study, a simulation was conducted using LEACHW sub-model. This sub-model can predict water movement in non-saturated soil based on Richards equation and is able to establish proper connections with the relationships of the irrigation scheduling. An experiment with four different maize varieties of hybridsingle cross as four replications and three treatments of without water stress (witness), short-term water stress and long term water stress were performed in two areas. The present study aimed at investigating the effect of soil texture in evapotranspiration formulas and evaluating the importance of evaporation compared to transpiration in the early days of cultivation and its conversion with time from the beginning of the growth period. The results showed that soil texture as an effective parameter should be incorporated in evapotranspiration relation. Moreover, the predicted cumulative evapotranspiration values were obtained as740, 640 and 520 mm for without water stress, short term water stress and long-term water stress treatments, respectively. However, the predicted evapotranspiration value by evaporation pan was 770 mm.

KEYWORDS: Water Stress, LEACHW Sub-Model, Evapotranspiration, Maize, Evaporation Pan

INTRODUCTION

Considering the vital importance of water in agriculture and the shortage of this vital element in Iran, the need for careful assessment is inevitable. Correct application and use of water is achieved when the amount of water for different purposes is specified. Precise measurement of evapotranspiration of plants creates the possibility to use water resources efficiently and prevent waste or vain use of water and it can be consumed based on needs. One of the criteria of simulation that can evaluate water movement in soil is LEACHW. It was one of the research models that if the input data are measured it can be used as a management model (Inskeep et al., 1994). In LEACHW model, evapotranspiration values were planned based on Childs and Hanks (1975) methods. Other methods can be applied after the changes made into the evapotranspiration sub-model plans including daily potential evapotranspiration calculation and daily potential perspiration calculation. Since the most common water movement in soil is unsaturated and it is mostly influenced by matric potential. Therefore, the most fundamental equation to express the unsaturated water movement in soil is Richards's equation (Richards, 1931). LEACHW is a model that uses water movement general equation in porous media to provide numerical solutions of water movement in soil. This model has five sub-models and LEACHW is one of them. It was proposed by Huston and Wagent (1992) and then was confirmed and used by other researchers as a powerful model that simulates water movement in soil (Chammas et al., 1997; Huston and Wagent, 1992; Soulsby and Reynolds, 1992).

Kong et al. (2001) presented a model for the study of water movement in soil profile which was used to stimulate the wheat harvest. Hydraulic parameters of soil and plant were determined using laboratory measurements. The results showed that there was a good fit between the simulated moisture, soil surface evaporation, plant transpiration and water absorption values and the calculated values. Baily and Spackman (1996) research indicated that for estimating soil moisture and values of evapotranspiration a model was presented. The input data consisted of the top layer of soil depth, the capacity of the lower and the upper layers of soil, the properties of plants and the climatic data. First, this model estimated evapotranspiration values and then considered and evaluated the effect of water stress on the obtained values of evaporation. Richards's equation was used in this model and there was a high correlation between the estimated and measured values. Evaporation pan was one of the simplest tools used to communicate with ET_o. The pans measured the effect of radiation, temperature and moisture in the process of evaporation from the surface of water (Elliote et al., 1998).

Although there were differences between evaporation pan and evapotranspiration from the surface of plants, using these pans to predict for 10 days or longer is more appropriate. Pans generally indicate higher evaporation than the

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actual evapotranspiration of the plants. Therefore, in order to adjust numbers pan coefficient seems necessary (Bay Bordi, 1989). Climate conditions greatly influence the numerical results as if it is only about ±40% of the actual value (Alizadeh, 2011). In arid and semi-arid areas evaporation from the surface water is an important component of water balance. In cases that the groundwater level is high, a significant amount of water from this source is evaporated by capillary rise from the soil surface. Evaporation causes gradual salinization of soil and is associated with water loss (Zarei Mahmoodabadi, 2010). Since evaporation is a natural and non-linear process; therefore, the researchers need to be careful in choosing appropriate methods for simulation (Parehkar, 1998). Nowadays, neural network researchers have achieved valuable results. The purpose of the current study is to evaluate LEACHW sub-model in accurate estimation of evapotranspiration values as well as the separation of the combined values.

MATERIALS AND METHODS

An experiment was conducted in two regions of Khorasan Razavi province including Torbat Heydarieh and Mashhad cities to investigate the process of evapotranspiration phenomenon in non-cultivated soil and soil under maize plant cultivation.

Torbat Heydarieh City

This design was done with two treatments of A and B with three replications. The treatments dimensions were A (1.5 × 1.5) and B (2×2) square meters. Treatment A profile had a depth of 150 cm with five layers (0-3-, 30-6-, 60-100, 100-130, 130-150 cm) and contained silty loam, loam, sandy loam and loamy sand textures, respectively. Plot B had a similar depth with three layers (0-10, 30-60, 60-150 cm) and loam, silty clay loan and silty loam textures. After sampling which was used to register the initial soil moisture conditions, utilizing calibrated gallon 40 to 225 liters equivalent to 100 mm of water was added to A and B treatments, respectively. The second irrigation was performed after 60 days. Regarding the fact that evaporation pan was installed at the project site, the average daily evaporation was measured by the drop in the water level in the evaporation pan. The distance between treatments A and B were selected about 1000 meters.

Mashhad City

In this study, the cultivated maize was examined in a randomized complete block design with three treatments and four replications. The replication dimensionswere (2.1×2.1), (2.1×1), (1.1×2.1) and (1.1×2.1) Sqm. The profile of these replications consisted of four layers (0-20, 20-80, 80-110 and 110-150 cm) that were scientifically called loam, sandy clay loamand sandy loam. Initially, various replication layers were sampled to remove the initial moisture condition. Four kinds of hybrid single cross maize (301, 604, 647 and 704) with the desired densities of 60000, 65000, 70000 and 75000 plants per hectare were cultivated in the evaluated replications. The investigated treatments included the first treatment without water stress, and the second treatment with short-term water stress. After preparing the land for seed sowing, the rows were made with the distance of 75 cm. Irrigation stresses were separately applied in each of the replications. In the treatments of without water stress, short-term water stress, and long-term water stress 11, 13 and 16 irrigations were performed, respectively. The first and the second irrigations were done with an internal of four days for the three treatments. After the second irrigation treatments of short-term and long-term water stress were not irrigated for 33 (70% depletion allowance humidity) and 53 (90% depletion allowance humidity) days, respectively. This was due to the irrigation time conflict of the cultivated maize plant and winter cereals. However, these two treatments were irrigated according to the costume of once each 10 days during the following period of maize cultivation. The criterion to enter the stress period for the two treatments of short-term and long-term water stress was reaching 70 to 90% of depletion allowance moisture. For different depths of soil bulk density, crop capability, wilting point, accessible water and hydraulic conductivity factors as model input important parameters were accurately measured. Model sensitivity analysis indicated that the LEACHW sub-model is very sensitive to bulk density. Therefore, this parameter was measured by the two methods of paraffin and cylinder.

RESULTS AND DISCUSSION

Determination of the Plant Water Requirement
Pan Evaporation Method

Pan evaporation is installed in most meteorological stations and is one of the simplest tools that if the amount of evaporation is accurately measured and recorded, the obtained statistics can be applied in determining plant water requirement in short-term periods of 10 days. The stages of plant growth are divided into the early stage of growth, plant development, the middle stage and the final stage (Alizadeh, 2011). The highest value of plant coefficient for maize was 1.23 which was determined in the 95th day. In its maturity condition, the maize plant covered about 0.8 of its cultivation area and, as a result, K_p pan coefficient which is a function of the type of pan, place of pan installation, average relative humidity and the wind direction before reaching the pan equals to 0.6 (Inskeep et al., 1994). In Figure 1, the actual evapotranspiration for maize plant was plotted based on the evaporation pan method. This suggests that if maize plant in Mashhad city is watered with 770 mm water, it can reach the final growth stages to be harvested.

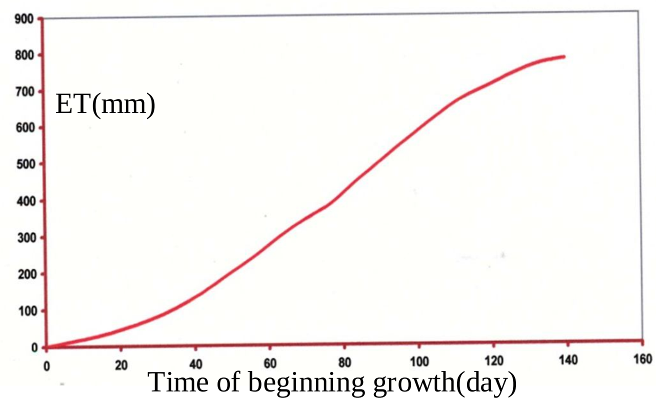

Figure 1: Actual evapotranspiration for maize plant

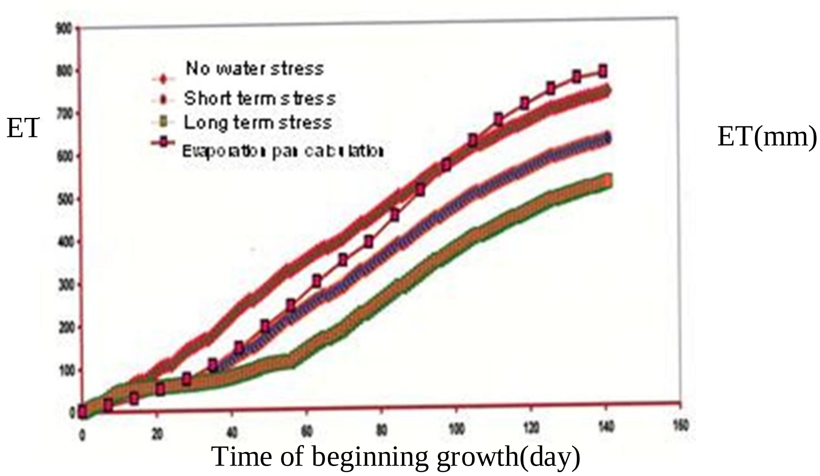

Figure 2: Comparison of the estimated values of the evapotranspiration calculated by the model and the evaporation pan

Overtime, the values of plant coefficient increased upto a specific point and then declined. Plant coefficient curve variations is a function of plant growth and the temperature with the constant evaporation pan coefficient, only the plant coefficient can help to accurately conclud evaporation pan results in warm or cool days.

LEACHW Sub-Model Prediction

The estimated values of maize plant by the model are displayed in Figure 2 in different cases of water stress. The maize plant curves were plotted and a graph was drawn in order to compare the estimated evapotranspiration values with the actual measured evapotranspiration values. In different treatments the amount of water in the irrigation was higher compared to real situations until the 21st day. Contrary to previous assumptions in which the efficiency in initial periods were stated to be low, the current results indicated that the two early heavy irrigations in the land under maize plant cultivation resulted in water storage in the second and third layers and the idea of the deep penetration of the irrigation water due to the lack of plant growth and the idea that the plants are pre-mature were not acceptable. The proof of evapotranspiration can be seen in various conditions of water stress. The values of the simulated maize plant evapotranspiration were higher than the obtained values of evapotranspiration using pan evaporation until the 106th day in the without water stress treatment. This may originate from the fact that water is stored in different soil profile layers of this treatment. In the early days, some water was evaporated in the form of evaporation and the others in the form of evapotranspiration. The root growth reached its highest level (i.e 91 cm) on the 109th day. In this case, because of the high transpiration of the plant until the end of the growing seasons, the evapotranspiration values estimated by the model for the without water stress treatment was lower than the obtained values estimated using evaporation pan. In the short-term water stress treatment, the evapotranspiration value estimated by the model was constantly lower that the calculated value using evaporation pan from the 21st day by the end of the growth period. However, days after the mentioned day the estimated evapotranspiration values by the model were constantly lower than the predicted evapotranspiration values by the evaporation pan. Although the cultivated plants in short-term and long-term water stress treatments were watered less than the actual amount of water, the two treatments reached their highest values regarding root growth, which indicated the crop performance due to the water stored in the soil profile. The cumulative evapotranspiration values predicted by the model for the treatments without water stress, short-term and long-term water stress were 740, 640 and 520. It is obvious that the early heavy irrigations are necessary for the plants that want to enter into a long period of stress. This is due to the fact that in this case the water is stored in the soil and based on the needs of plant water will be offered to the plant.

Estimating of Evapotranspiration Using LEACHW Sub-model

Soil without Plant Cultivation

Evaporation is the only phenomenon that can be done from the soil without cultivation surface of A and B. All formulas that predict evapotranspiration are dependent on meteorological parameters. The findings of researchers on soil without cultivation indicated that the only influential factors on the amount of evaporation for the soil surface are not meteorological parameters. In fact, soil texture plays a significant role in evaporation from the soil surface. The presence of a parameter in evapotranspiration estimation equations that represents the soil physical characteristics seems to be mandatory. Cumulative evaporation values were similar for different textures until the tenth day. This may result from the presence of sufficient soil moisture in the soil profile. But overtime as the soil profile dries, soil textures determines the way moisture is provided by different types of soils. Generally, soils with heavy texture indicate more evaporation than soils with light texture. This is due to higher water store capacity of soils with heavy texture than the soils with light one. Thus, the coefficient effect on evapotranspiration formulas indicating the soil characteristics is quite tangible.

Soil with Plant Cultivation

Analyses of the evapotranspiration phenomenon in different treatments are displayed in Figure 3. Evaporation from soil surface without water stress is too way higher compared to short and long-term water stress treatments. It could be due to the early heavy irrigation and water storage within the soil profile layers.

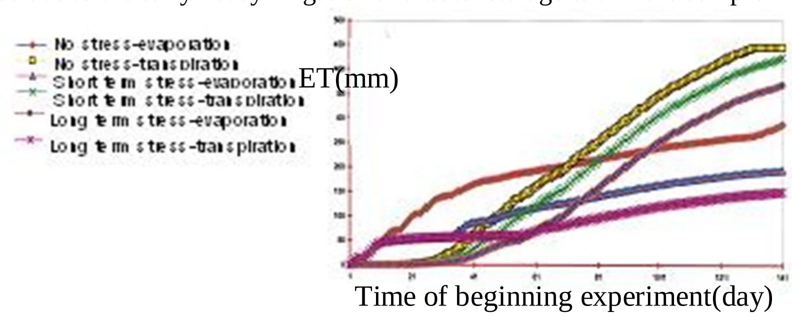

Figure 3: Separation of evapotranspiration values in different treatments of irrigation

Since the plant roots were shallow until the 21st day, the transpiration values were similar to each other (about 10 mm) in different treatments of irrigation. In the early days of growth due to lack of growth in 3 different irrigation treatments the evaporation rate was higher than the transpiration rate. The values of evaporation in without water stress, short-term and long-term water stress treatments were 100, 50 in the 21st day, respectively. However, the evapotranspiration values for the treatments of without water stress, short-term and long-term water stress in days of 72, 63 and 59 were equal to each other. These values in the referred days were 394, 235 and 153. From the mentioned date later, the majority of evaporation rates prioritized over transpiration rate due to the plant growth and the transpiration phenomenon increased considerably. If the input data are properly selected and inserted, satisfactory results will yield. If the criteria for irrigation are based on the available water in soil,satisfactory results will not be achieved. This means that soil with similar volumetric moisture and different soil textures displayed different patterns in providing the water in their soils. Therefore, it is recommended to provide water moisture curve to determine the irrigation time so that they are irrigated based on the reliable parameters of soil water potential. The results showed that lack of application of soil characteristics in the calculations of plants evapotranspiration is a significant factor for not reaching the actual amount of evapotranspiration. It is recommended to modify the existing evapotranspiration formulas for arid and semi-arid soils. The total amount of evaporation and transpiration rates in different irrigation treatments indicated the plant evapotranspiration in the associated treatment. Since the amount of water in soil profile in treatment of without water stress is more than short term and long term water stress treatments, the evaporation increasing pattern was from without water stress treatment to long-term water stress. This suggested that the more is the amount of water in soil profile, the higher will be the evapotranspitation process as shown in Figure 2.

Conclusion and Recommendations

The evaluation of water movement in soil was conducted using LEACHW sub-model. This model had a relatively high efficiency in estimating volumetric moisture. It can calculate the water requirements of plants accurately and prevent water loss areas and the effect of the physical characteristics is applied. In a fixed area with one type of plant cultivation and two texturesthe water requirements of crops are totally different. That is, that soil texture plays an important role in losing or providing water for the plant while the importance of this parameter is not included in any formula for water requirements. In the early days, the number of heavy irrigations with short period of irrigation will increase so that the plants are resistant to water stress periods. Deficit irrigation is a management practice that can provide water to the plant using scientific methods. The studies indicated that in the initial stage of plant cultivation in soil only the water within soil is largely evaporated due to lack of roots and theaerial parts of the plant. However, with time and the growth of root and aerial parts of the plant, transpiration effect increased. It should be noted that in the first ten days the evaporation rate was identical for all different irrigation treatments, while in the first 22 days the transpiration rate was identical for all the treatments. It can be implied that until the twenty-second day short-term and long-term water stress treatments indicated no difference regarding their transpiration rate.

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