SOIL EVAPORATION IN SURFACE AND SUBSURFACE DRIP IRRIGATION IN A MAIZE FIELD

L'ÉVAPORATION DU SOL EN SURFACE ET SUBSURFACE DANS IRRIGATION GOUTTE UN CHAMP DE MAÏS

Hanieh Kosari¹, Hossein Dehghanisanij², Farhad Mirzaei³, Abdol-Majid Liaghat⁴

ABSTRACT

Evaporation reduction is one of the advantages of drip irrigation. A research was conducted in summer 2009 at experimental station of AERI, Karai-Iran on maize field to measure soil surface evaporation by BREB method in two irrigation systems of surface and subsurface drip irrigation systems. In surface drip irrigation, the drip tapes placed in nearest place to the crops and along the crop rows and in subsurface drip system, driptapes placed 0.15 m below soil surface under the crop rows. Four components of soil surface energy balance including net radiation reaching soil surface (R_{ns}), soil surface heat flux (G), sensible heat flux (H_s) and soil latent heat flux (λE_s) were calculated and discussed in two systems. Daytime average of energy balance components in terms of (w/m²) and also soil surface evaporation in terms of (mm/day) were calculated in both irrigation systems. During measurement period, net radiation values ranged between 304 to 333 w/m² which caused net radiation reaching the soil surface ranged between 67 to 107 w/m² in both systems. As it was expected R_{ns} values decreased with crop growth and leaf area index (LAI) increased later in crop development period. Soil heat flux accounted for about 36 to 53% of R_{ns} in surface drip irrigation and about 17 to 25% in subsurface drip irrigation. As it was shown, daytime soil heat flux values were greater in surface drip irrigation. As it was shown, λE_s accounted for about 41 to 63% of R_{ns} in surface drip irrigation while it was about 56 to 71% in subsurface drip irrigation. It was observed that the ground in both surface and subsurface drip irrigation became wet but reverses direction of moving water in subsurface system, may contribute to more evaporation in subsurface drip irrigation. Accordingly, subsurface drip irrigation systems on depth of emitter lateral line should be taken into more consideration.

¹⁻ M.Sc., Dept. of Irrigation and reclamation Engineering, Agricultural and natural resources Campus, University of Tehran, Karaj, Iran, email:hk_kosari@yahoo.com

²⁻ Assistant professor, Agricultural Engineering Research Institute, Karaj, Iran,

email:dehghanisanij@yahoo.com

³⁻Assistant professor, Dept. of Irrigation and reclamation Engineering, Agricultural and natural resources Campus, University of Tehran, Karaj, Iran, email: fmirzaei@ut.ac.ir

⁴⁻ Professor, Dept. of Irrigation and reclamation Engineering, Agricultural and natural resources Campus, University of Tehran, Karaj, Iran, email: aliaghat@ut.ac.ir

1. INTRODUCTION

Development of applied and reliable methods of measuring evapotranspiration components plays an important role in crop growth modeling and farm irrigation management. Except initial crop growth stage soil evaporation include smaller proportion of evapotranspiration and since it is not directly related to crop yield it is discarded. While it is an important loss in initial crop growth stage. Soil evaporation can be measured with different methods. In some methods soil evaporation is measured by water balance using microlysimeters (conaway and Van Bavel, 1967; Boast and Robertson, 1982). But there is limitations using of microlysimeters since the soil inside the microysimeter is hydraulically isolated and it may dry differently from the undisturbed around soil (Ashktorab et al., 1989) and also when evaporation is small, microlysimeters don't result correctly (Ham et al.,1990). In some other methods soil evaporation is measured indirectly by measuring both evapotranspiration and crop transpiration by a reliable method and calculated from subtracting these two values. With these methods evaporation precision is dependent on the precision of the two other parameters. Furthermore by different measuring place of these two parameters correlation may not exist between the calculated and actual soil evaporation.

Bowen ratio energy balance is one of the simplest and most applicable methods of latent heat flux measurement. This method has been widely used on different conditions and the results showed it is one of the reliable methods evapotranspiration measurement. In a research by Ashktorab et al, (1989), in California University, soil evaporation was measured by Bowen ratio energy balance from a bare soil. Results showed good correlation between soil evaporation measured by Bowen ratio energy balance and microlysimeter measurements. Therefore it was suggested a method for measuring soil evaporation under crop canopy (Ashktorab et al, 1989). Then this method was used in other researches for measuring soil evaporation under maize canopy (zeggaf et al., 2008) and tomato (Ashktorab et al., 1994) and showed good results. Therefore the idea for using this method for soil evaporation measurement under conditions that other methods have limitations was made.

Micro irrigation systems especially drip irrigation can reduce soil evaporation. But correct design and perfect management should be applied to reach this advantage. This issue when initial investments increase becomes important. In this regard detailed research can improve information. The aim of this research is to measure soil evaporation in surface and subsurface drip irrigation by Bowen ratio energy balance method.

2. MATERIAL AND METHODS

2.1. Experimental site

The research was conducted in summer 2009 at experimental station of agricultural engineering research institute (AERI), Karaj-Iran ($35^{\circ} 21' \text{ N}$, $51^{\circ} 38' \text{ E}$, 1312.5 m above sea level). The field soil was prepared for planting in spring. Results from soil experiments up to 80 cm below surface showed the soil type was loam texture (47 % sand, 44 % silt, 9 % clay) with EC_e=1.7.Maize crop (Double Cross 370) was planted on 15 June 2009. The crop was planted with 0.75 m row width and north-south orientation. Therefore the experiment site was a 40×60 m² field (Fig 1). The field was bordered by irrigated maize field except in western side which was unplanted. Irrigation water was supplied from the well and chemical quality analysis showed water in this region has good quality. A drip-tape irrigation system with 0.30 m dripper distance was used to apply irrigation water. Drip tapes were positioned 15 cm below the soil surface for making sub-

surface drip irrigation in 14 rows of eastern part of the field. Depth of positioning was selected based on previous researches in this area and also financial resources in the project. For the rest of the field drip tapes were placed on soil surface in nearest place to the plant rows. Crop water requirement was estimated based on longtime meteorological data (averaging from 1988 to 2008) and calculation of crop evapotranspiration by method recommended in FAO 56 (Allen et al., 1998). From the early crop growth period 20% over irrigation based on 3 day intervals was applied to prevent water stress. At the period of this experiment 41-44 and 59-62 day after emergence (DAE), leaf area index (LAI) was measured in 41, 44, 59, 62 DAE. Each time 3-5 plants were selected randomly and the whole leaf area of a plant was measured with leaf area meter (Area Measurement system, DELA-T Devices, ENGLAND) in the laboratory. Then LAI was calculated from multiplying the average plant leaf area by plant density. LAI values for the days between the days of measurement obtained by linear interpolation (Gardiol et al., 2003). Automatic weather station was established in the field simultaneously with start of experiment period and hourly average values of solar radiation (R_s), air temperature, relative humidity and wind speed were measured and logged continuously.





2.2. Energy balance theory at soil surface

Energy balance at soil surface can be expressed as:

$$R_{ns} - \lambda E_s - H_s - G = 0 \tag{1}$$

Where R_{ns} is the net radiation reaching the soil surface, λE_s is the soil surface latent heat flux, H_s is sensible heat flux and G is soil heat flux (all units of wm⁻²). In equation (1) the convention used for the signs of the energy fluxes is R_n positive downward and G is positive when it is conducted downward from the surface, λE and H are positive upward. R_{ns} was determined by the empirical equation (2) with R_n and LAI which has been used previously by some other authors (Zeggaf et al., 2008, Kato et al., 2004, Gardiol et al., 2003, Stockle and Jara., 1998).

$$R_{ns} = R_n \exp(-0.622 \text{LAI} + 0.055 \text{LAI}^2)$$
 (2)

Partitioning of energy between λE_s and H_s is determined by the BREB (Bowen., 1926, Zeggaf et al., 2008, Ashktorab et al., 1989) by the following equation:

$$\beta_{\rm S} = \frac{{\rm H}_{\rm S}}{\lambda {\rm E}_{\rm S}} \tag{3}$$

Assuming equality of eddy transfer coefficients for sensible heat and water vapor in the averaging period and measuring air temperature and vapor pressure gradients between the two levels, the Bowen ratio (β_s) is calculated by:

$$\beta_{\rm S} = \gamma \frac{\Delta \mathbf{T}}{\Delta \mathbf{e}} \tag{4}$$

Where ΔT and Δe are air temperature and vapor pressure differences between the two measurement levels and γ is psychrometric constant which is calculated by the following equation:

$$\gamma = C_{p} P / \varepsilon L_{v}$$
 (5)

Where C_p is the specific heat of air at constant pressure (1.01 kj kg⁻¹ c^{o-1}), P is atmospheric pressure (kpa), ϵ is the ratio between the molecular weights of water vapor and air (0.622), and L_v is latent heat of vaporization (kj kg⁻¹). Psychrometric constant for the experiment site was determined 0.058 (kpa c^{o-1}).

using equations (4) and (5) and measurement of air temperature and vapor pressure gradients near the soil surface, Bowen ratio at soil surface was determined. By solving equation (1) and (3) simultaneously, latent heat flux from the soil surface was determined by equation (6).

$$\lambda E_{s} = \frac{R_{ns} - G}{1 + \beta} \tag{6}$$

2.3. Energy balance measurements

From 41-44 and 59-62 DAE, soil evaporation (E_s) were determined by measuring all energy fluxes at soil surface simultaneously in two irrigation systems by two repititions which seprated by 5 m distance. Energy balance equipments in each measuring repetition consisted of a net radiometer (CNR1, Kipp&Zonen), two soil heat flux plates (MF-180M, EKO Japan) and two handmade thermocouple ventilated psychrometers for Bowen ratio measurement at soil surface. The details of constructed psychrometers have been described in Kossari (2009). Measuring systems in sub-surface drip irrigation were placed 8.5 m from the east edge of the field as the system number 2 was positioned 5 m from the south edge to maximize fetch to height ratio when prevailing wind (northwestern to south eastern) were present (Fig 1). That was greater than minimum adequate ratio reported by (Heilman et al., 1989) for measuring Bowen ratio during our experiment period. Measurement equipments in each measurement system were installed on a tall rod. Two ventilated psychrometers used for measuring temperature and water vapor gradients at soil surface were fixed 0.1 m apart on the rod as the lowest one was positioned 0.05 m above the soil surface (Ashktorab et al., 1989, Zeggaf et al., 2008). Net radiometer also installed 1 m above crop canopy to measure the total net radiation available at field level. Soil heat flux was measured with two soil heat flux plates positioned 0.02 m below the soil surface, one in plant row and the other in plant row aisle. All data were measured every minute by a CR23X datalogger connected to an AM16/32 multiplexer (Campbell Scientific, Inc., UT) and averaged 30 min intervals.

3. RESULTS AND DISSCUTION

3.1. Meteorological parameters

Daytime average values of meteorological parameters measured by the automatic weather station in experiment period are shown in table (1). Plant in days 41- 44 DAE was in developing stage and in days 59-62 DAE was in mid-season stage. Irrigation has been done on 41, 44, 59 and 63 DAE, which exceptionally because of some problems the last one irrigated with 4 days interval. In the experiment period the 42 and 60 DAE received maximum and minimum solar radiation respectively.

Table 1. Daytime average values of meteorological values in experiment period (Jour des)
valeurs moyennes des valeurs météorologiques période d'expérimentation)

Growth Stage	DAE	Air Temperature (c°)			Relative Humidity (%)			Wind	Solar
		Min	Max	Ave	Min	Max	Ave	- Speed (m/s)	MJ/m2day
Developing Stage	41	16.67	34.44	24.10	18.92	78.16	53.02	2.90	45.17
	42	16.51	34.07	24.12	15.64	83.07	52.64	3.38	46.82
	43	16.10	33.30	23.39	26.80	77.82	54.09	2.95	46.21
	44	16.56	32.89	23.79	28.66	74.72	52.16	2.92	44.31
Mid-Season stage	59	19.91	37.38	28.30	12.42	65.51	36.40	1.48	40.97
	60	19.96	35.64	27.42	17.78	65.98	41.67	2.33	40.14
	61	19.09	35.57	27.00	13.29	72.40	41.68	2.05	45.18
	62	16.00	34.45	24.24	13.06	59.69	38.43	1.90	45.07

3.2. Energy balance measurements

Daytime average of energy balance measurements in terms of (w/m2) at soil surface in two irrigation systems are shown in table (2). Net radiation values which was measured in only one irrigation system due to lack of instrument ranged between 304 to 333 (w/m2). It was considered correctly because all effective parameters on net radiation such as climate and meteorological conditions, soil texture, crop, soil surface color, etc. were the same in two irrigation systems. Then since leaf area index (LAI) measurement resulted the same values in two irrigation systems, net radiation reaching the soil surface (R_{ns}) was the same. Since there was short irrigation interval in drip irrigation the crop root zone area and also soil surface was wet. Therefore there were no significant changes in net radiation before and after irrigation. Net radiation measurements also showed R_{ns} values decreased with crop growth and LAI increase as would be expected later in measurement period.

Latent heat flux at soil surface accounted for about 32 to 60 (w/m2) in surface drip irrigation and and 40 to 73 (w/m2) in subsurface drip irrigation. As it was shown in table

(2) soil latent heat flux accounted a large portion of the net radiation as would be expected under nonstressed conditions (Ham et al., 1991) and it was about 41 to 63 % in drip irrigation and 57 to 71 5 in subsurface drip irrigation system.

Soil heat flux accounted for about 25 to 47 (w/m2) in surface drip irrigation and 17 to 25 (w/m^2) in subsurface drip irrigation which is equal to 36 to 53 % and 18 to 31% of net radiation reached soil surface in surface and subsurface drip irrigation respectively.

Soil surface energy balance measurements showed R_{ns} partitioned primarily between soil heat flux and latent heat flux and there was very little sensible heat flux.

Table 2. Daytime average energy fluxes at soil surface in surface and sub-surface drip irrigation (Jour les flux d'énergie moyenne à la surface du sol dans l'irrigation goutte à goutte de surface et du sous-sol).

Daytime average energy fluxes at soil surface										
Sub-Surface Drip irrigation										
G/R ₀₀	$\lambda Es/R_{ns}$	λEs	G	R _{ns}	DAE					
	%		DAL							
21	59	63	23	107	41					
18	71	73	19	104	42					
26	56	54	25	96	43					
26	66	58	23	88	44					
29	71	50	20	70	59					
25	64	43	17	67	60					
28	69	49	20	71	61					
31	57	40	22	70	62					
	Daytime average energy fluxes at soil surface									
		Surface Drip	o irrigation							
G/R _{ns}	G/R_{ns} $\lambda Es/R_{OO}$		λEs G R _{DD}							
	%		DAE							
44	51	55	47	107	41					
43	58	60	44	104	42					
48	41	39	46	96	43					
53	44	39	47	88	44					
49	46	32	34	70	59					
45	52	35	30	67	60					
39	59	42	28	71	61					
36	63	44	25	70	62					

3.3. Diurnal energy balance pattern for a sample day

Despite of discussion on daytime averages of energy balance components, evaluation of its diurnal pattern contains of more useful information too. Diurnal trends of the energy balance components at soil surface for both irrigation systems in 60th DAE are shown in figure (2). This day was selected because it is representative of a cloudy day. Average air temperature and relative humidity was 27.4 C° and 41.6 % respectively. Daytime average

of net radiation available at maize field was 304 wm^2 which was the smallest value in the measurement period. Maximum R_n and G were 674 and 140 wm² which occurred some minutes before and after 13:00 h respectively. As it is shown in figure (2), variation of R_n values is not symmetrically as a bell shape curve signifies that there were some cloud cover at sky during the day.

During the daytime of 60th DAE only 22% of net radiation reached the soil surface. Most of the energy was split between λE_s and G and H_s was small. λE_s was less than available energy except in the afternoon suggesting that the soil surface was absorbing energy from within-canopy air stream which provided energy for λE_s . Similar signification was reported in Ham et al., (1991) for soil surface energy balance relationships. Daytime average of λE_s was about 0.94% of (R_{ns}-G) and only about 6% of (R_{ns}-G) was used as sensible heat While Zeggef et al, 2008 reported R_{ns}-G was split between λE_s (0.52%) and Hs (48%) at maize field (LAI=1). β_s ranged from -0.2 to 1.2 but typically ranged between -0.2 to 0.5 at this day.



Figure 2. Diurnal trend of energy balance components at soil surface in surface and sub-surface drip irrigation (tendance diurne des composantes du bilan énergétique à la surface du sol dans l'irrigation goutte à goutte de surface et du sous-sol)

4. Conclusion and recommendations

As it was shown daytime soil heat flux values were greater in surface drip irrigation. It may caused by heat convection in surface drip irrigation while moving down the water from the surface and higher temperature of water when drip tapes were positioned on the ground. Therefore available energy for soil evaporation, Rns-G, was lower in surface drip irrigation. As it was shown λ Es accounted for about 41 to 63% of Rns in surface drip irrigation while it was about 56 to 71% in subsurface drip irrigation. It was observed the ground in both surface and subsurface drip irrigation became wet but reverse direction of moving water in subsurface system, as may contributed to more evaporation in subsurface drip irrigation systems on depth of lateral line which carrying the emitters.

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