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Evapotranspiration Partitioning in Surface and Subsurface Drip Irrigation Systems

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1. Introduction

Water transfer from the soil-plant system to the atmosphere occurs through evapotranspiration, which includes evaporation of water from the soil and other surfaces and transpiration through plant stomata. Evaporation is the process whereby liquid water is converted to water vapor (vaporization) and removed from the evaporating surface (vapor removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation. Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere. Transpiration, like direct evaporation, depends on the environmental factors including energy supply, vapor pressure gradient and wind. Hence, radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate. The transpiration rate is also influenced by crop characteristics, environmental aspects and cultivation practices. Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes (Allen et al., 1998).

Where the evaporating surface is the soil surface, the amount of water available at the soil surface is the main sources of evaporation. Accordingly any irrigation method which decreases the water availability in the soil surface will decrease the evaporation considerably. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. The degree of shading of the crop canopy is other factors that affect the evaporation process. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.

Evapotranspiration (ET) partitioning into soil surface evaporation (E_s) and crop transpiration (T_c) is fundamental to many irrigation management studies. In many cases such as design of irrigation system, measurement of the whole ET is sufficient but when the research on water consumed by crop become more precise measurement or estimation of its two components, E_s and T_c, will be valuable. Prime attempts to partition ET include methods covering the ground surface of a plot to eliminate E_s and measure water loss by crop (Tc) and compare it with water loss by uncovered plot (ET) to reach E_s (Harrold et al., 1959; Peters and Rassel, 1959; Shaw, 1959). The researches showed, applying ground cover to partition ET changes the field and soil surface energy balance and does not estimate crop transpiration accurately in natural condition ((Fritschen and Shaw, 1961). Developing micro-lysimeter (Boast and Robertson., 1982), provided E_s measurement directly without drastic changes in soil and field condition caused by surface covers (Shawcroft and Gardner., 1983). Applying this method simultaneously with ET measurement at the same place provides ET components separately (Ham et al., 1990; Jara et al., 1998; Sepaskhah and Ilampour, 1995). Some results showed there are some limitations with using micro-lysimeter especially when E_s consisted small portion of ET (Ham et al., 1990, Jara et al., 1998). Additional researches applied ET measurement simultaneously with transpiration measurement frequently using sap flow gauges. Sakuratani (1987) was first who reported ET components separately in this way (Ham et al., 1990). In some of those researches micro-lysimeter was used for evaluating the accuracy of measured E_s with the calculated ones. Ashktorab et al. (1989) measured E_s by Bowen ratio energy balance from bare soil. Then they applied it with ET measurement using weighing lysimeter to partition ET components. Their results suggest an accurate method to measure E_s under the crop canopy (Ashktorab et al., 1994). The latest work on partitioning ET was method applying Bowen ratio energy balance (BREB) to measure both ET and E_s (Zeggaf et al., 2008). Their results showed this technique can provide a framework for partitioning ET at maize field simply and economically to previous methods (Zeggaf et al., 2008).

Applied and precise methods of ET partitioning provide useful data for farm irrigation management and water use efficiency improvement. This knowledge particularly for modern irrigation systems implementing with high costs is more important, where E_s reduction is one of the advantages of modern irrigation systems such as surface drip irrigation (DI) and subsurface drip irrigation (SDI). Accurate and efficient management should be applied to reach such advantages of these systems. Subsurface drip irrigation (SDI) is an alternative to conventional drip irrigation, which would become an attractive option to most of the farmers in arid and semi arid regions like Iran. The advantages of SDI compared to surface drip irrigation include direct application of water to the root zone, less E_s, potentially greater water use efficiency and fewer weed and disease problems (Phene et al, 1991). SDI reduced tillage using semi-permanent beds (Senn and Cornish, 2000) and removed the need for deep cultivation between the crops. SDI has been found to increase yield over surface drip (Sakellarious-Makrantonaki et al., 2002); furrow irrigation (Hanson et al., 1997); and sprinkler irrigation (De Tar et al., 2004), providing the SDI system receives good irrigation scheduling (Haman and Smajstrla, 2002).

Soil and canopy energy balances have some interactions in crop environment and irrigation systems change this environment significantly which may has influences on ET. Sprinkle irrigation increase the air humidity, surface irrigation keep the soil surface wet for at least one day after irrigation and, drip irrigation decrease the crop water stress by short irrigation interval. Toward a precise irrigation management, measuring ET component is required to have confidence on development of new and precise irrigation systems such as SDI. Besides, relation between the effective factors in ET could provide us valuable information for better farm irrigation management and water use efficiency improvement. Based on our knowledge, there is no information on proportion of E_s or T_c component under SDI, where soil surface kept dry and that may increase the soil surface temperature during the day time. In this chapter we are going to show how we could partition ET for SDI and DI systems in a maize field using a BREB method and discuss energy balance elements variation under these two irrigation systems.

2. Energy balances theories

2.1 Energy balance theory at maize field

Energy balance at field level can be expressed as:

$$R_n = G + H + \lambda E \tag{1}$$

Where R_n is net radiation reaching the field, above the maize canopy, λE is latent heat flux, H is sensible heat flux and G is soil heat flux (all units of W/m^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. Partitioning of energy between λE and H is determined by the BREB (Bowen., 1926, Perez et al., 1999) by the following equation:

$$\beta = \frac{H}{\lambda E} \tag{2}$$

where β is the Bowen ratio. By solving equation (1) and (2) at the same time the following expressions for λE and H are obtained:

$$\lambda E = \frac{R_n - G}{1 + \beta} \tag{3}$$

$$\mathrm{H} = \beta \frac{\mathrm{R_n} - \mathrm{G}}{1 + \beta} \tag{4}$$

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) is calculated by:

$$\beta = \gamma \frac{\Delta T}{\Delta e} \tag{5}$$

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:

$$\gamma = C_p P / \varepsilon L_v \tag{6}$$

Where C_p is the specific heat of air at constant pressure (1.01 kJ/kg °C), 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). Psychrometric constant for the experiment site was determined 0.058 (kPa/°C).

2.2 Energy balance theory at soil surface

Energy balance at soil surface can be expressed as:

$$R_{ns} - \lambda E_s - H_s - G = 0 \tag{7}$$

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 from the soil surface (all units of W/m^2). R_{ns} was determined by the empirical equation (8) with R_n and LAI which has been used previously by some other authors (Gardiol et al., 2003; Kato et al., 2004).

$$R_{ns} = R_n \exp(-0.622\text{LAI} + 0.055\text{LAI}^2) \tag{8}$$

Bowen ratio at soil surface was calculated similar to the energy balance computation at field level with the following equation:

$$\beta_s = \frac{H_s}{\lambda E_s} \tag{9}$$

which using equations (5) and (6) and measurement of air temperature and vapor pressure gradients by ventilated psychrometers near the soil surface, Bowen ratio at soil surface was determined. By solving equation (7) and (9) simultaneously, latent heat flux from the soil surface was determined by equation (10).

$$\lambda E_s = \frac{R_{ns} - G}{1 + \beta} \tag{10}$$

2.3 Energy balance theory at crop canopy

Energy balance at maize canopy can be expressed as below (Zeggaf et al., 2008, Ham et al., 1991):

$$R_{nc} = \lambda E_c + H_c \tag{11}$$

where R_{nc} is net radiation absorbed by crop canopy, λE_c is crop canopy latent heat flux and H_c is crop canopy sensible heat flux (all units of W/m^2). Applying the principle of continuity and the definition of R_n, it can be shown that R_{nc}, equation (12), is the difference between R_n measured above and that below the maize canopy (Ham et al., 1991).

$$R_{nc} = R_n - R_{ns} \tag{12}$$

Canopy latent heat flux was calculated from equation (13):

$$\lambda E_c = \lambda E - \lambda E_s \tag{13}$$

Then H_c was calculated as a residual from equation (11).

3. Methodology development

The research was conducted in summer 2009 at experimental station of agricultural engineering research institute (AERI), Karaj-Iran (35° 21′ N, 51° 38′ 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 ECe=1.7. Irrigation water were supplied from underground well with an quality which had no negative impact for maize (EC=0.8 dS/m and pH=7.8).

The experimental field was defined in an area of 40×60 m^2 in selected site (Fig. 1). A day before planting 50 kg potash fertilizer was added to soil and maize (Double Cross 370) was planted on 15 June 2009. The crop was planted with 0.75 m row width and north-south orientation. The field was bordered by irrigated maize field except in western side which was unplanted.

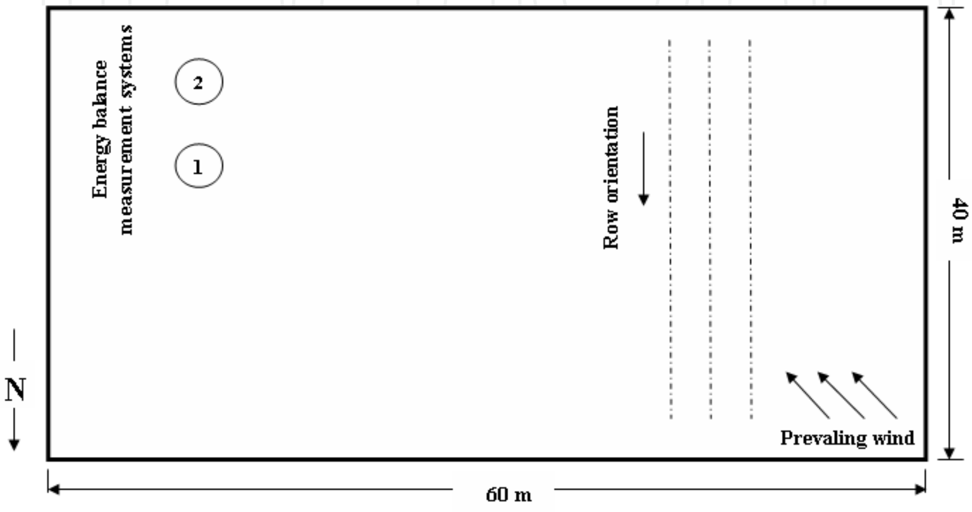

Fig. 1. Schematic diagram showing field position and location of energy balance measurement systems.

Irrigation water was supplied from the well and chemical quality analysis showed water in this region has good quality. A subsurface drip-tape irrigation system with 0.30 m dripper distance was used to apply irrigation water. Drip tapes were placed 15 cm below the soil surface in nearest place to the plant rows. Special attention was paid while positioning drip tapes to transfer water correctly. Crop water requirement was estimated based on long time meteorological data (averaging from 1988 to 2008) and calculation of crop ET by method recommended in FAO 56, Penman Monteith Method (P-M) (Allen et al., 1998). The P-M method is recommended for the Karaj area by Dehghanisanij et al. (2004). From the early crop growth period 20% over irrigation based on 3 day intervals was applied to prevent water stress. Recommended nitrate fertilizer (according to soil experiments it was 400 kg/ha) was distributed during the crop growth period and closely to crop establishment place by irrigation system (fertigation). 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 (Rs), air temperature, relative humidity and wind speed were measured and logged continuously.

From 41-44 and 59-62 DAE, ET and Es were determined simultaneously by measuring all energy fluxes at maize field and soil surface using two independent measurement systems.

Then by subtracting the latent heat flux at soil surface from the latent heat flux at maize field (ET), transpiration was obtained. Energy balance equipments consisted of a net radiometer (CNR1, Kipp & Zonen), two soil heat flux plates (MF-180M, EKO Japan) and four hand made thermocouple ventilated psychrometers for Bowen ratio measurement in both field level and soil surface. The details of constructed psychrometers have been described in Kosari (2010). Two independent measuring systems separated by 5 m distance, were placed 9 m from the east edge of the field as the system number 2 was positioned 5 m from the east edge to maximize fetch to height ratio when prevailing wind (north-western 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 field level above the crop. These two psychrometers were installed 1 m apart as the lowest one was positioned 0.2 m above the crop canopy (Ham et al., 1991; Jara et al., 1998). The remaining two psychrometers used for measuring temperature and water vapor gradients at soil surface. These two psychrometers 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). Net radiation at field level was measured with net radiometer installed 1 m above crop canopy. Soil heat flux was calculated as an average of two soil heat flux plates positioned 0.02 m below the soil surface. All data were measured every minute by a CR23X data logger connected to an AM16/32 multiplexer (Campbell Scientific, Inc., UT) and averaged 30 min intervals.

4. Meteorological parameters variation

Daytime average values of meteorological parameters measured by the automatic weather station in the 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.

Growth stage	DAE	Air Temperature (°C)			Relative Humidity (%)			Wind Speed (m/s)	Solar Radiation MJ/m^{2}day
		Min	Max	Ave	Min	Max	Ave		
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

Table 1. Daytime average values of meteorological values in experiment period.

5. Evapotranspiration analysis

Diurnal trend of evapotranspiration measurement by BREB method compare to evapotranspiration estimation by P-M method for 60 and 61 DAE are shown in Fig. 2. These days were selected because they are representative of cloudy and clear sky condition respectively which is believed they show all sky condition during measurement period.

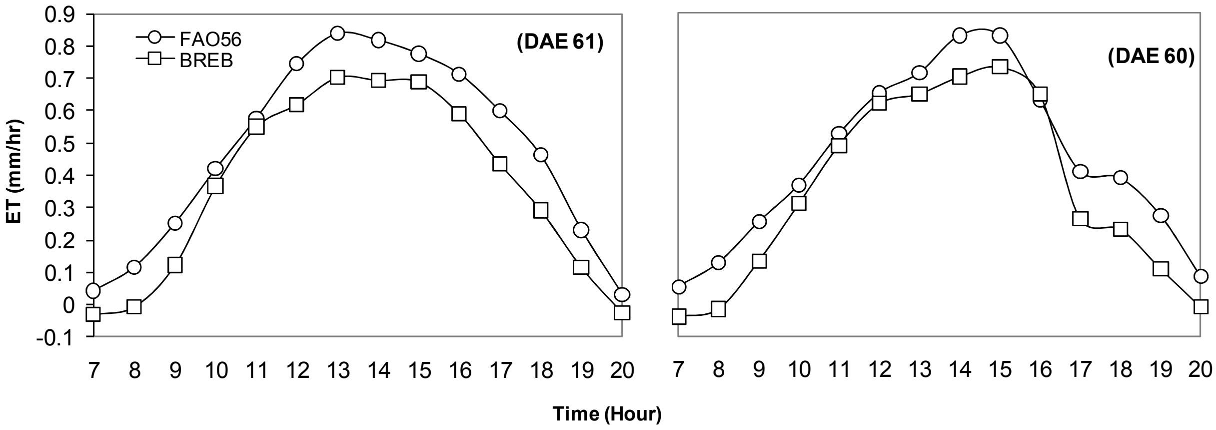

Fig. 2. Diurnal trend of evapotranspiration by BREB and P-M method for 60 and 61 DAE.

As it is shown in Fig. 2 both methods have the same trend and a good correlation (R^2=0.92 and 0.95 for DAE 60 and 61, respectively). Therefore evapotranspiration by BREB showed 9% variations compare to P-M method which can be acceptable. Positive value of MBE parameter shows overestimation of P-M method compare to BREB. These differences can be caused by different measurements of effective and required parameters in both methods. In other word, BREB evapotranspiration was obtained by direct measurement of required parameters at field level and soil surface while in P-M method maize evapotranspiration was obtained by estimation of reference evapotranspiration and crop coefficient. Ortega et al. (1995) found a good correlation between refernce evapotranspiration by BREB and Penman method on irrigated grass.

6. Energy balance at farm level

Daytime average of energy balance measurements in terms of (W/m^2) at Maize field, soil surface and crop canopy for DI and SDI are presented in tables 2 to 4. In the measurement period net radiation values ranged from 304 to 333 (W/m^2) resulted by the minimum and maximum solar radiation in corresponding days respectively (Table 2). Latent heat flux (λE) From the Maize field ranged from 207 to 267 (W/m2) for SDI and 197 to 296 (W/m2) for DI. According to the results λE ranging from 62 to 83 % of R_n under SDI and 61 to 94 % for DI, which shows maize cropping system is under non-stressed conditions (Ham et al., 1991). Herein G/R_n was ranging 6 to 8 % for SDI and 8-15 % for DI, which is close to 10 % reported by Yunusa et al. (2004).

Soil surface energy balance measurements showed R_{ns} values decreased with crop growth and canopy cover increment. Furthermore it showed R_{ns} partitioned primarily between soil heat flux and latent heat flux from the soil surface and there was very little sensible heat flux during experiment period. The G variation under SDI was 17 to 25, and it was 25 to 47

W/m² in under DI. The λEs accounted for about 40 to 73 (W/m²) in SDI, where maximum value of λE_s was 60 W/m² for surface DI. Accordingly, $\lambda E_s/R_{ns}$ and G/R_{ns} ratios ranged between 56 to 71 % and 18 to 31 % respectively (Table 3). The G under SDI was much less compared to that under DI during crop developing stage than mid-season stage. It is while, λE_s was larger under SDI compared to that for DI. These results contributed to higher possible potential for T under SDI during crop developing stage (Table 3).

DAE	R_n	Subsurface drip irrigation (SDI)				Surface drip irrigation (DI)			
		G	λE	$\lambda E/R_n$	G/R_n	G	λE	$\lambda E/R_n$	G/R_n
	W/m²			%		W/m²		%	
41	322	23	-	-	7	47	197	61	14
42	333	19	207	62	6	44	266	80	13
43	329	25	212	64	8	46	255	78	14
44	320	23	242	76	7	47	243	76	15
59	315	20	247	78	6	34	296	94	11
60	304	17	235	77	6	38	253	83	10
61	326	20	248	76	6	28	271	83	9
62	322	22	267	83	7	25	245	76	8

Table 2. Daytime average energy fluxes at maize field.

DAE	LAI	R_{ns}	Subsurface drip irrigation (SDI)				Surface drip irrigation (DI)			
			G	λE_s	$\lambda E_s/R_{ns}$	G/R_{ns}	G	λE_s	$\lambda E_s/R_{ns}$	G/R_{ns}
		W/m²			%		W/m²		%	
41	2.20	107	23	63	59	21	47	55	51	44
42	2.38	104	19	73	71	18	44	60	58	43
43	2.56	96	25	54	56	26	46	39	41	48
44	2.74	88	23	58	66	26	47	39	44	53
59	3.50	70	20	50	71	29	34	32	46	49
60	3.53	67	17	43	64	25	30	35	52	45
61	3.57	71	20	49	69	28	28	42	59	39
62	3.60	70	22	40	57	31	25	44	63	36

Table 3. Daytime average energy fluxes at soil surface.

Daytime average of energy balance measurements at Maize canopy showed λE_c increased by crop development from 134 to 227 (W/m²) which resulted $\lambda E_c/R_{nc}$ between 58 to 90% in SDI. These ratios showed canopy latent heat fluxes were often lower than available energy which resulted some sensible heat flux conducted away from canopy level. Under DI, λE_c increased by crop development from 142 to 264, which was less in average compare to that for SDI (Table 4).

7. Diurnal energy balance pattern

Diurnal trends of the energy balance components for the soil surface of maize field at 60th DAE are shown in Fig. 3. This day was representative of a day with some cloud cover in the sky. 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 W/m², which was the smallest value in the measurement period.

DAE	R_{nc}	Subsurface drip irrigation (SDI)		Surface drip irrigation (DI)	
		λE_c	$\lambda E_c/R_{nc}$	λE_c	$\lambda E_c/R_{nc}$
	W/m²		%	W/m²	%
41	215	-	-	142	66
42	230	134	58	205	89
43	233	158	68	216	93
44	232	184	79	204	88
59	245	197	80	264	108
60	237	192	81	218	92
61	255	199	78	229	90
62	252	227	90	201	80

Table 4. Daytime average energy fluxes at crop canopy.

During the day Maximum R_n and G were 674 and 70 W/m², which occurred about 13:00 and 14:00 h respectively. As it is shown in Fig. 3 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.

Most of (R_n-G) was used to drive λE and β values ranged between 0 to 0.7 while β values reported by Zeggaf et al., (2008), in maize field was lower than 0.25. It can be due to different crop growth stage in two experiments (in this research during the 60th DAE, Maize crop covered the ground relatively complete, LAI=3.53) and various climate, soil type and/or irrigation system. Sensible heat flux accounted for about 18% of available energy (R_n-G). Similar results were reported by Steduto and Hsiao, (1998), Ham et al., (1991) and Ritchie, (1971). Soil heat flux was about 17 (W/m²) which was lower than 10% of net radiation as it is found a recommended value for daytime average of soil heat flux in literature (Allen et al., 1998).

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. The value of H_s was small in this balance. The 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 86% of R_{ns}-G and only about 14% of R_{ns}-G was used as sensible heat. During this day βs from soil surface, ranged from -0.5 to 0.5. Positive H_s values at soil surface indicates convective transport of heat away from the soil surface (Zeggaf et al., 2008), but the results from this research showed small amounts of available energy used as sensible heat flux. Field observations from subsurface drip irrigation system showed installation depth of drip tapes caused during irrigation, water rises up to the surface and makes the ground wet. Therefore the large proportion of soil surface latent heat flux from available energy can be due to the ground wetness. It can be concluded when drip tapes install in lower depth and the soil surface remains dry larger proportion of sensible heat will result.

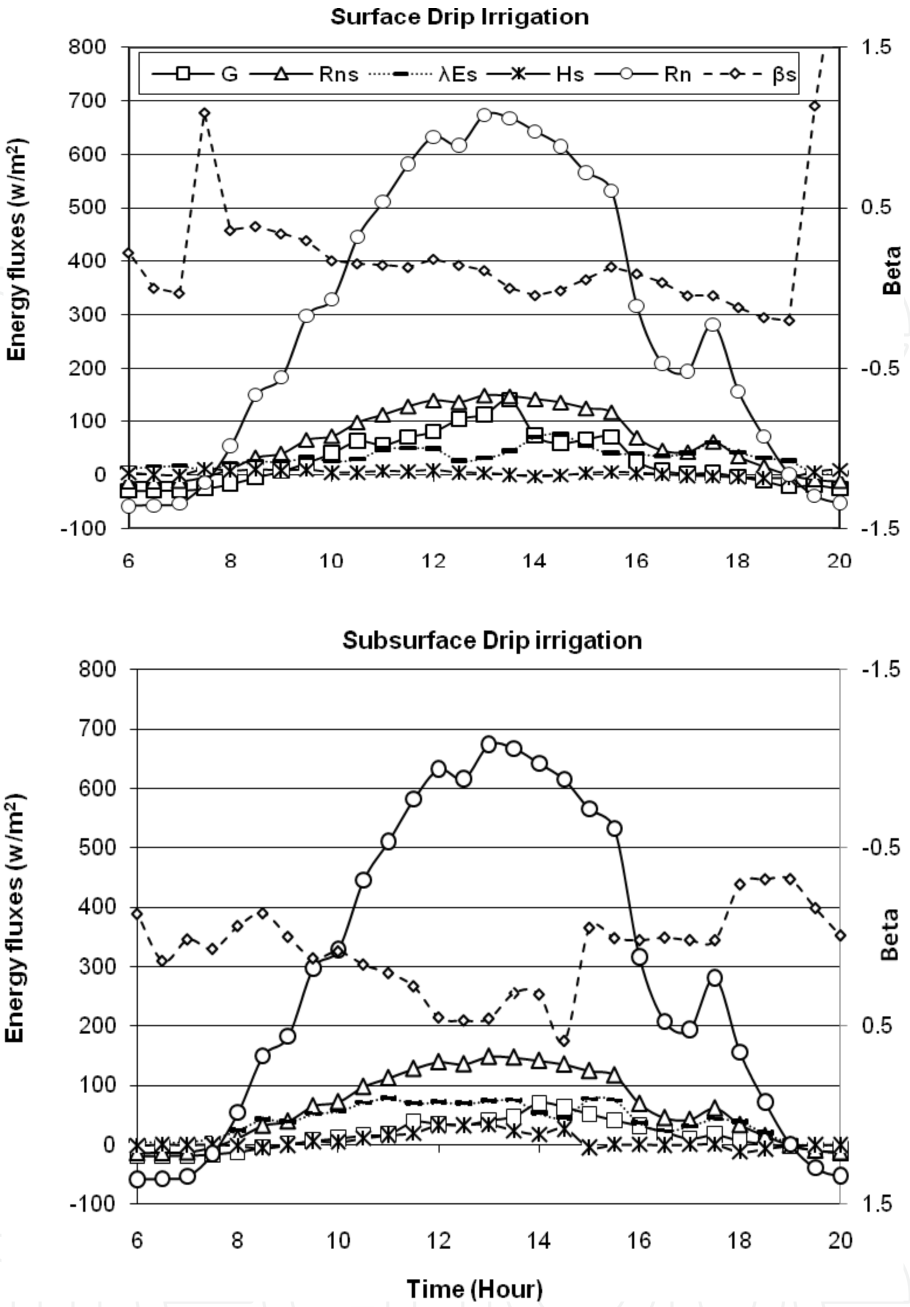

Fig. 3. Diurnal trend of energy balance components at soil surface of maize field in 60th DAE under surface and subsurface drip irrigation.

Available energy (R_n-G) and λE from maize field for the 60th DAE are shown in Fig. 4. The linear regression lines between λE and R_n-G were obtained with high values of r^2=0.99 for both SDI and DI. Based on the slope of the trade lines in Fig. 4, there was no a significant reduction in available energy to the maize field and soil surface between two irrigation system. Accordingly, SDI aimed at reducing soil evaporation compared to DI, is not effective when soil surface covered by canopy (LAI=3.5).

Available energy (R_{ns}-G) and λE_s from soil surface for 41th DAE are shown in Fig. 5. The 41th DAE presenting crop developing stage, when LAI was about 2.20. Accordingly, there was a wide scattering for available energy under DI which might be because soil surface is not uniformly wet under DI. However, the condition under SDI was uniformly and a linear regression lines between λE_s and R_{ns}-G were obtained.

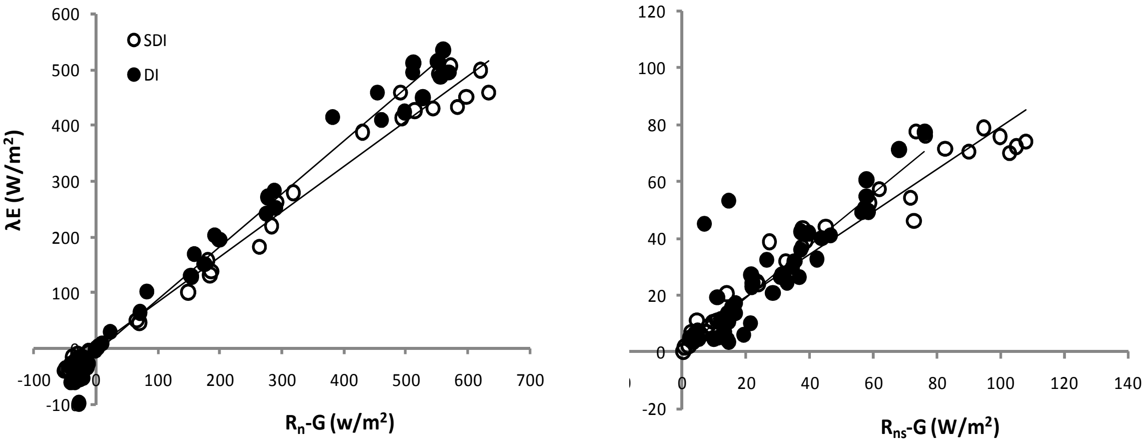

Fig. 4. Available energy (R_n-G) and latent heat flux (λE) from maize field and soil (R_{ns}-G and λE_s) in 60th DAE for surface (DI) and subsurface (SDI) drip irrigation.

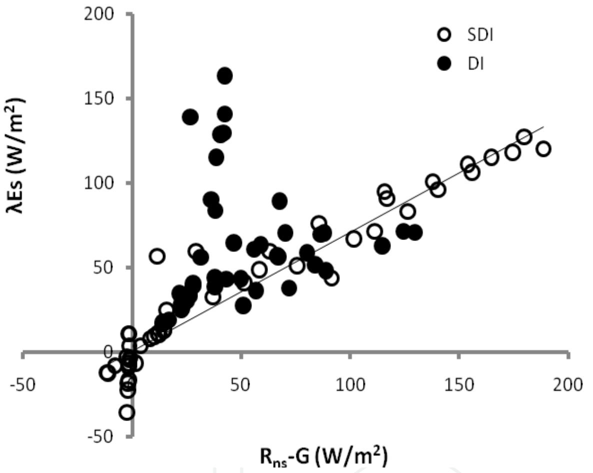

Fig. 5. Available energy (R_{ns}-G) and latent heat flux (λE_s) from soil surface in 41th DAE for surface (DI) and subsurface (SDI) drip irrigation.

8. Conclusion

The Bowen ratio method could be used for partitioning ET under surface (DI) and subsurface drip irrigation system (SDI). Partitioning ET for advance irrigation system could provide us useful information for better irrigation management during crop growth stages and development of new irrigation technique. Partitioning ET and measurement of energy balance over maize field, canopy and soil by Bowen ratio showed that soil had major impact on the energy balance between the soil and canopy when soil surface is not covered fully by crop canopy. In crop developing stage, energy balance of maize field was different under DI and SDI. This result could be contributed to more difference between the systems in early crop development stage, when soil surface is not covered fully by crop canopy.

As it was shown daytime soil heat flux values were greater under DI (25-47 W/m^2) compared to that under SDI (17-25 W/m^2). It may caused by heat convection in DI 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, R_{ns}-G, was lower in DI. As it was shown λE_s accounted for about 41 to 63% of R_{ns} in DI while it was about 56 to 71% in SDI. It was observed the ground in both DI and SDI became wet but reverse direction of moving water in subsurface system, as may contributed to more evaporation in SDI. According to the results, more consideration should be applied using SDI systems on depth of lateral line which carrying the emitters, canopy size, crop type, and plant water stress affect soil and canopy energy balances. Those data will be useful for validation of ET models.

9. Acknowledgment

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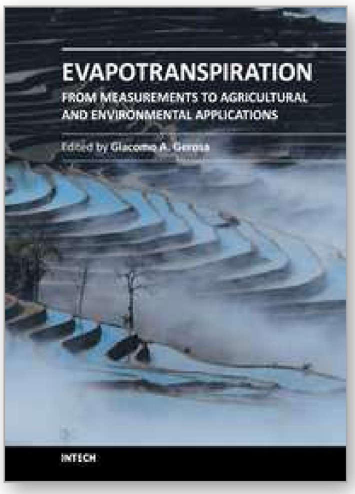

Evapotranspiration - From Measurements to Agricultural and Environmental Applications
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This book represents an overview of the direct measurement techniques of evapotranspiration with related applications to the water use optimization in the agricultural practice and to the ecosystems study. Different measuring techniques at leaf level (porometry), plant-level (sap-flow, lysimetry) and agro-ecosystem level (Surface Renewal, Eddy Covariance, Multi layer BREB), are presented with detailed explanations and examples. For the optimization of the water use in agriculture, detailed measurements on transpiration demands of crops and different cultivars, as well as results of different irrigation schemes and techniques (i.e. subsurface drip) in semi-arid areas for open-field, greenhouse and potted grown plants are presented. Aspects on ET of crops in saline environments, effects of ET on groundwater quality in xeric environments as well as the application of ET to climatic classification are also depicted. The book provides an excellent overview for both, researchers and student,s who intend to address these issues.

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