INTERNATIONAL JOURNAL OF ENHANCED RESEARCH IN SCIENCE TECHNOLOGY & ENGINEERING
VOL. 2 ISSUE 1, JAN.-2013 ISSN NO: 2319-7463

Energy balance on Soil - Tree Canopy System through Urban Heat Island Mitigation

Ahmed Hasson[1], Hussain Alaskari[2], Muhsin Jweeg[3]
[1]Desertification,Climate Change, Mechanical Engineering Dept., College of Engineering, Nahrain university Jaderia, Baghdad,Iraq
[2]Archeticture Department, College of Engineering, Nahrain university, Jaderia, Baghdad, Iraq.
[1]dr_ahasson@yahoo.com

Abstract: Baghdad is a large city, warmer than surrounding areas due to the urban heat island effect. The study is to determine the energy balance influenced the heat and mass transfer in soil water within the soil- trees canopy system. Bowen ratio techniques were used to obtain the field energy balance, including total latent heat flux. Soil latent heat flux was calculated from the differences between LE and LEc. These measurements were coupled with radiation measurements at the soil surface to partition the energy balance into soil and canopy components every hour throughout the daytime. Daily energy balance was strongly influenced by sensible heat flux transfer, and the radiation balance alone did not account for the magnitude or diurnal pattern of LEs and LEc. When the soil surface was wet after rainfall, LEs accounted for more than 87 % of LE even when LAI greater than 2.0 m^2/m^2.

Keywords: Energy; Latent heat; Net radiation; Sensible heat; Urban Heat island ; Baghdad.

I. Introduction

The lack of urban vegetation such as trees and shrubs contributes to the heat island effect. Trees serve to cool surrounding air through evapotranspiration [1]. When plants undergo photosynthesis they release water vapour, which evaporates upon release and cools the surrounding air. In general, it is thought that vegetation plays a larger role in the regulation of surface temperatures than do non-reflective surfaces [2]. Non-impervious surfaces will absorb precipitation, and it can be evaporated slowly from the soil. Trees can reduce air conditioning use through a decrease in ambient temperature, thereby reducing ozone production and greenhouse gas emissions. Strategically planted vegetation decreases energy use in three ways. First, shading windows helps prevent direct solar radiation from entering a building. Second, the tree will reduce the amount of radiation hitting the roof and walls, reducing the amount of radiation reaching the structure. Last, shading affects the energy use by cooling the soil around the house that can act as a “heat sink” for the house [3].

Larger trees also tend to be more effective, as they provide a greater canopy cover and shade area. Parkland with a certain percentage of tree cover may not have the same temperature as a nearby residential block with the same tree cover. Furthermore, because high tree cover is often associated with low building density, it is difficult to determine what variable – trees or buildings – is primarily responsible for observed conditions. Wind speed, air temperature and humidity all influence the effect that trees will have on an urban climate. Trees also serve to indirectly reduce energy production and cost by cooling surrounding air through evapotranspiration [1].

Another study found maximum midday air temperature reductions due to trees are in the range of 0.04ºC and 0.2ºC per percent canopy cover increase [4]. There is considerable uncertainty as to the magnitude of the effect of evapotranspiration on urban temperature, but multiple simulations suggest that it can produce savings greater than that of direct tree shading [5]. It has been suggested that if all urban tree spaces were filled, and if rooftops and parking lots were painted lighter colours, electricity use in the U.S. would be reduced by 50 billion kilowatt hours each year, thereby reducing the amount of CO2 released into the atmosphere by as much as 35 million tons per year [6]. The strategic placement of trees is also important with respect to evapotranspiration. The reason being is that each tree has a certain radius of “cooling power”, a radius that depends on characteristics such as tree size, species, etc. Spread out vegetation prevents overlap as well as maximizes the area that will be affected by the cooling affects of evapotranspiration. Additional studies need to be conducted to evaluate the effect of trees on mitigating the urban heat island. Because the urban heat island is largely a night-time phenomenon, one study suggests, that while trees help lower day-time air temperatures by shielding incoming solar radiation, extensive tree cover also inhibits re-radiation and heat loss at night, keeping surface temperatures high [7]. The effect is especially maximized during times when diurnal temperature differences are minimal, such as during the summer months.

Crop energy balance is determined by the measurements of heat and water vapor and a Bowen ratio to calculate the energy balance of canopy vertical layer [8,9]. Sensible heat from the soil and lower part of tree leaves could increase the latent heat of the upper part of the crop canopy [10]. While [11]Kanemasu,(1974) indicated that the high temperatures within canopy resulting in sensible heat transport to the soil surface and upper canopy [12] found that leaves temperature lower than the soil temperature by 20 ^{o}C and that 21 % of canopy flux absorbed from the oil surface. Sensible heat transported from the crops to the soil did influence the soil latent heat. Canopy latent heat can also influence canopy and soil latent heat [13] Fuch, (1972) [14] suggest that the canopy and soil energy balance measurements are needed on time scale comparable to the transfer processes themselves. Canopy latent heat was effected by air temperature more than soil latent heat and soil latent heat could account for almost half of the field latent heat [15]. The objective of this study was to determine the soil - tree canopy diurnal energy balance in the city of Baghdad.

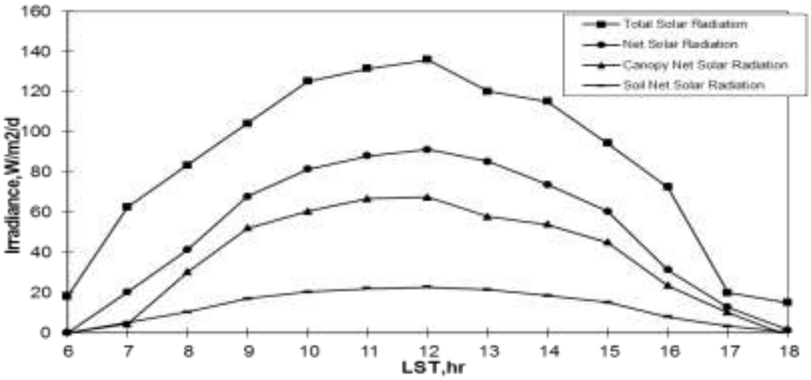
II. Experiment Site

The study conducted during the summer, 2011 at the University of Baghdad campus is located 5 km south of Baghdad city centre, 33^{o} 14` N latitude and 44$^{o}$ 14`E longtude at the elevation of 34m above M.S.L

Table 1. Environmental weather data for the JDs, 198 and 220 at the experimental site.

Julian date	Ambient Temp,min, C	Ambient temp.Max.C	Min.RH, %	Max.RH, %	Rainfall, mm	Wind speed, km/h	Et, mm
198	19.3	44.2	28.5	44.3	0	9.0	3.1
220	27.3	48.1	32.2	40.1	0	16.6	3.9

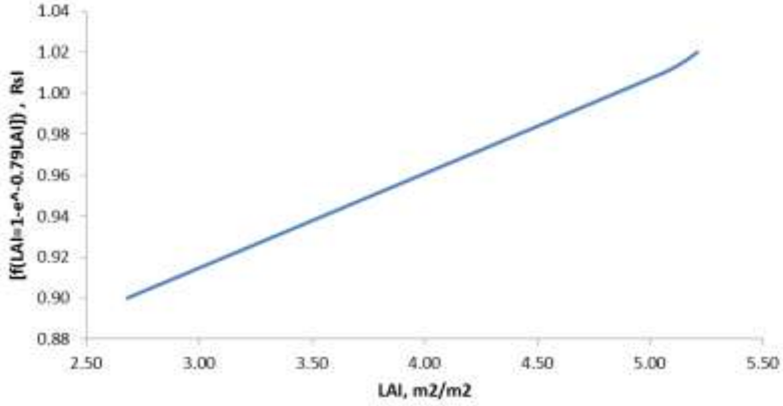
(Fig.1). The climate of the study area is semi-arid and sub-tropical with very little rainfall and frequently light to heavy sand storms during summer months, [16]. Irrigation is mostly used twice a week during summer months.
The experiment block, has an area of 0.5 ha. The trees were established on line of flat soil surface within 2.5 m spacing. Most of the trees are mulberry planted on the south, east and west side. The sidewalk is 20%. The soil site is a brown sandy loam with a platy cultivation traffic pan. The soil surface is covered by shorter vegetation.



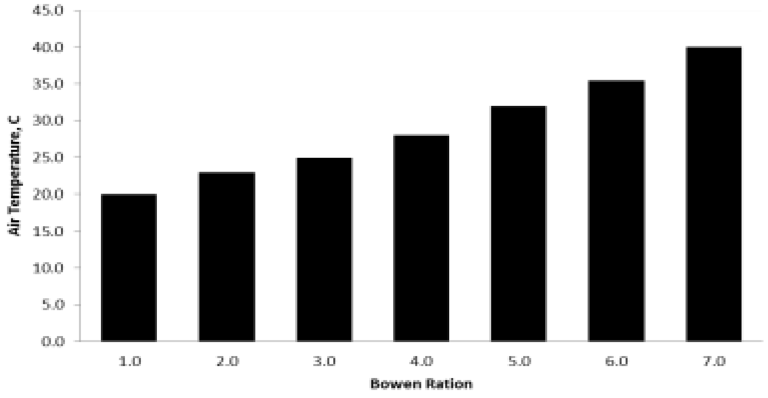
III. Measurements and Calculations

The quantity of radiant energy remaining at the earth surface (net radiation) is the energy available contains important processes except the energy associated with the photosynthesis . The surface energy balance is written as follows :

$$Rn + LE + H + G = 0 \qquad (1)$$



Bowen ratio method was used to determine the field energy balance [17]. The Bowen ratio energy balance was measured on the The University of Baghdad campus on Julian dates 198 and 220. Direct measurements of soil heat flux were done by using calorimeter. The plates were made according to [18] method at 5 cm depth. The heat flux from the soil surface to the 5 cm depth was determined by measurements of the temperature changes with time by using copper constabtan thermocouples. The heat flux was calculated as mentioned by [16] :



$$G = [\,(Cg\rho + \theta)\,(\Delta T/\Delta t)\,\Delta z] \qquad (2)$$

The exchanges between the wet and dry bulb psychrometers were used to measure the temperature and the vapor pressure gradients according to[19] at the height of 3m above the ground level. The latent heat flux was then calculated as

$$LE = (Rn - G)/(1 + \beta) \qquad (3)$$

This equation has been used over different kinds of plants where extremely dry conditions are not used. The maximum possible error in LE was analyzed according to [20].

Measurements of the total global solar radiation was made with Black-and-White Epply pyranometer Model 4-48 . The instruments were mounted horizontally with its sensing surface at a height of 3m. Net radiation was similar in design to those described by [21,22].

The instruments were measured with miniature net radiation radiometer MNR which was mounted horizontally with its sensing surface at 0.5m and 3m above the ground and parallel to the row midway between trees. All supplemental instrumentation was positioned upwind the center of the plot. Net radiation of the canopy is the different radiation net radiation above and below the trees.

$$Rnc = Rn - Rns \qquad (4)$$

It is worth noting that this relationship has been analyzes explicitly [24].
The latent heat flux density from the surface was calculated as :

$$LEs = LE - LEc \qquad (5)$$

[23] concluded that this relationship makes good correlation between the calculate and the measured values of LEs. The energy balance of the trees can be seperated into its soil and canopy which can then be written as [24]

$$LEc = Rnc - Hc \qquad (6)$$

The surface energy balance of the canopy can be expressed as :

$$Rnc + LEc + Hc = 0 \qquad (7)$$

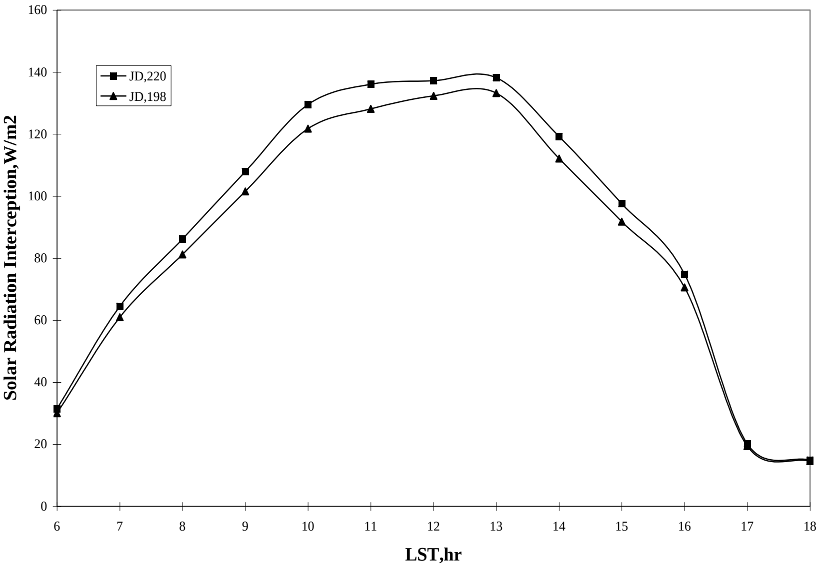
The sesible heat flux density from the canopy can then be calculated as from equation (7):

$$Hc = - (Rnc + LEc) \qquad (8)$$

The sensible heat flux from the soil will be obtained as:

$$Hs = - (Rns + LEs + G) \qquad (9)$$

Automatic data acquisition control equipment Model 3054 A was synchronized to provid the components of the energy balance at daytime hourly intervals. Soil moisture content of a 0 - 5cm depth of soil was determined gravimetrically daily for specific period. Soil bulk density as well as the moisture content for the 5cm depth were determined from the mean of the three undisturbed 7.6cm diameter core samples taken from the center of the block. Air temperature was measured within the canopy with aspirated thermocouples at height of 0.5m and 3m above the ground level (Table 1). Specific heat of the soil was 0.35 cal/gm/day. Leaf area index was measured by sampling 5 random trees and multiplying the measured LAI by the tree density.
Additional measurements includes tree height and width were conducted. Microclimatological measurements such as wind speed and relative humidity were conductd on hourly basis.



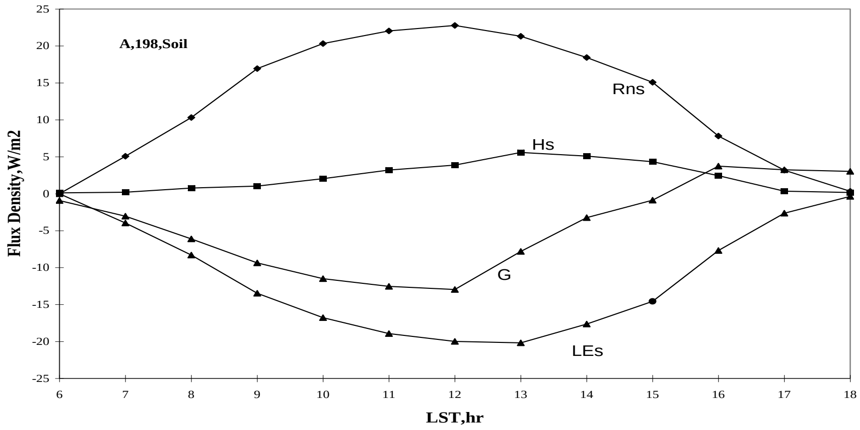
IV. Results

The meteorological data of the monthly average of daily total solar radiation is shown in (Fig.2). Baghdad is considered to be the dry lands in by which water consumption is high and may be needed the most. Low level rainfall (<160mm/year) is possible during winter months. Fig.3 shows the solar radiation weighting function, f(LAI) to an LAI of the tree canopy is intercepting about 95 % of the solar radiation . The extinction coefficient of that, 0.79 obtained from [25] . The leaf area index of the trees were varied between 2.5 and 5.0 m^2/m^2 during the period JD, 198 to JD, 220 (Fig.3). Figure 4 shows the estimation of the solar radiation interception by the canopy. The solar radiation interception was computed on a unit of leaf area index as follows:

$$RsI = Rs\ (1 - \exp(-0.79\ LAI)) \qquad (10)$$

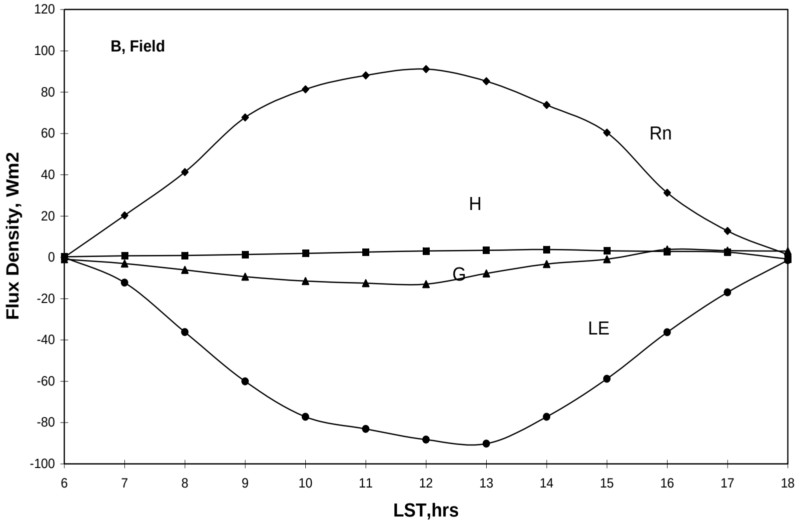
Julian date, 220 had the direct soil conditions during the study, and the diurnal pattern of radiant energy on the canopy showed dramtic increase near 1300 h(Fig. 4). Solar radiation inteception was lower on JD, 198, but still represented a significant energy source for the canopy. After irrigation, a much cooler soil surface reduced the thermal radiation on canopy. the thermal radiation from the soil and also influence the pattern as well as the magnitude of LEc, took place when the soil surface was dry. These conditions may need to consider that the mid row soil surface temperature measurements and the opaque view factor model may have caused an overestimating of RsI near mid day.

A good agreement among the Bowen ratio systems was observed. There was variation in Rn despite changes in soil surface conditions. Large portion of the energy is accounted in the LE the under non stressed conditions. Slightly stable condition was noticed above the canopy due to the positive H on JD,220. Soil heat flux accounted for 5 to 21 % of Rn and was slightly larger early in the study when the canopy was small when the LAI was decreased. Complete energy balances of the field soil and canopy were obtained for 2 days during the study. Skies were mostly partial cloudy and dusty on the days of measurements with exception of JD, 198 and 220. Surface volumetric water content was 0.30 to 0.41 cm^3/cm^3 and the soil surface bulk density was 1.38 g/cm^3. The fluxes of the heat toward the surface is considered to be positive, while the heat fluxes away from the surface is considered to be negative. Measurements were made between JD,198 and JD,220. Fig. 5 (A), shows the energy balances of the field canopy and soil for JD, 198 . The soil energy balances shows the soil was absorbing sensible heat from within - canopy airstorm (Fig. 5C). Since the Hc above the canopy was small most of the Hs originated from the conopy. The convective heat from the canopy and high Rns caused the LEs to be the principle form of LE near midday. However, between 1100 and 1200 h, G was over 30 % of Rs + Hs. This shows that while soil heat flux was a minor component of the daily energy balance, it played a crucial role in how energy was partitioned on a diurnal basis. Negative Hc values indicate that the sensible heat flux away from the canopy (Fig. 5 B) enhanced by cool arial and soil surface conditions. The loss of convective energy reduced the amount of available energy for LE. Also the diurnal pattern of LEc was in corelation , but less than the diurnal pattern of Rnc. Fig. 5 shows the detailed energy balance of the field, soil and canopy for the JD, 220. The field energy balance indicates that the nutral conditions were present in the morning with some sensible heat advection occuring in the afternoon (Fig. 5 A). Net radiation above the field followed diurnal course of solar radiation, there the soil heat flux reached 15 W/m^{-2} at 1300 h. The energy balance of the soil shows that Rns increased rapidly near 0800 h as soil irradiance increases (Fig. 5 C). Sensible heat flux from the soil was possitive from 0600 h to 1300 h ,and negative during the rest of the day due to the changing of wind speed near the soil surface. G and LEs were almost identical until 1500 h when G began to decrease in magnitude. The energy balance of the canopy on JD 146 shows that Rnc increased rapidly and then reach a plateau near 100 W/m^2 between 1100 h and 1200 h(Fig. 5 B). Possitive Hc values indicated that the canopy was absorbing sensible heat throughout the day, with maximum values near 48 W/m^2 occuring at 1500 h (Fig. 5 B). Advective energy caused LEc to exceed Rnc and skewed the Lec curve toward the afternoon. Inspection of Fig. 6 B and 6C shows that the Hc and Hs were toward the canopy .



Field energy balances for JD, 198 and JD, 220 were almost identical while soil and canopy energy balances were quite different**,(**Figs. 5-6). This demostrates that field energy balance measurements alone provide virtually no information on how energy balances of the soil and canopy are partitioned. The sensible heat flux for the field,soil and canopy for JD,220 was negliglble due to mesoisathermal conditions within the soil- plant atmosphere contonuum. As air and soil temperature increased throughout the day, the magnitude of Hc and H also increased. Negative Hs and positive H indicated that the sensible heat was converging on the canopy from two directions. Thus, the canopy was obserbing sensible heat. Figures 5 and 6 shows that the magnitude and direction of sensible heat transfer within above the canopy had a major influence on the diurnal pattern of the LEs and LEc.

The pattern of the sensible heat flux on JD, 198 shows an almost direct exchange of sensible heat between the canopy and soil. Soil surface temperature were low after the rainfall, creating an energy since at the soil. Sensible heat flux from the canopy was greater near midday where Hc contributed about 30 % of the available energy of the soil surface. Thus Hc increased soil evaporation and caused the LEs to exceeded LEc, near midday(Fig. 5). Results indicated that 13 % of the incident energy at the soil surface was due to the sensible heat advection and about 70 % of this energy came from the canopy .

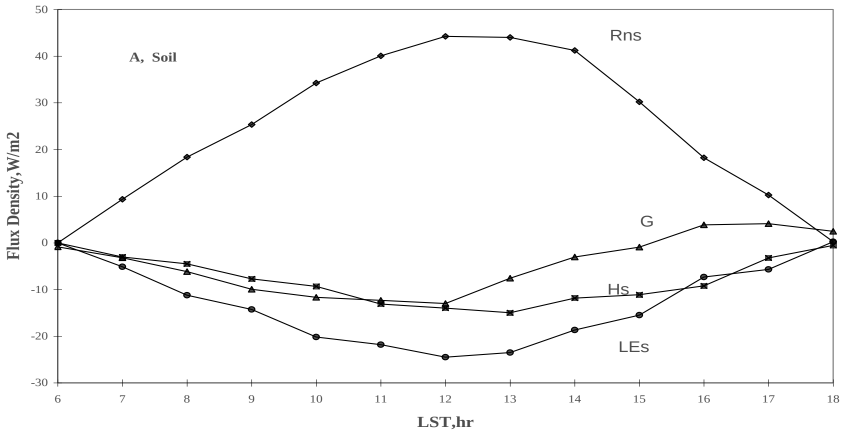


V. Discussion

A. Field energy balance

The energy balance illustrated by Figs.5-7 is well understood as is its relationship to planetary boundary layer characteristics. The heat energetic of the system is driven by the surface net radiant flux density which is dominated by short-wave radiation exchange by day and solely due to long-wave radiation at night. The surface radiant energy surplus (deficit) is dissipated (supplied) by heat conduction to (from) the underlying soil *and* by convection of sensible and latent heat to (from) the air *(*RnH and Rile respectively). The actual sharing of heat between the soil and the air depends upon many factors including the nature of the surface, the thermal properties of the soil and the state of the atmosphere (especially the level of turbulence).

A surface covered by short vegetation apportions about 80-90% of the daytime radiant surplus to the air but, at night, the irradiative deficit is balanced largely by conduction of heat from soil storage drawn from the atmosphere due to the relatively suppressed state of turbulent activity. The partitioning of the turbulent transport between the sensible and latent forms (Bowen’s ratio,) largely depends upon surface moisture availability. When the surface is wet, evapotranspiration is at the potential rate and is dependent only on energy availability and temperature [26]. When the surface is moist, rather than wet, the rate drops to about 80% of the potential value, a condition known as equilibrium evaporation.



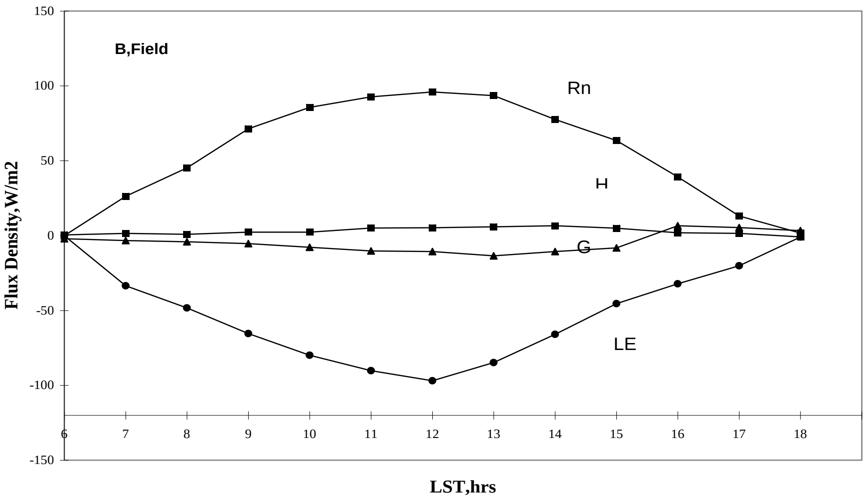
B. Canopy layer energy balance

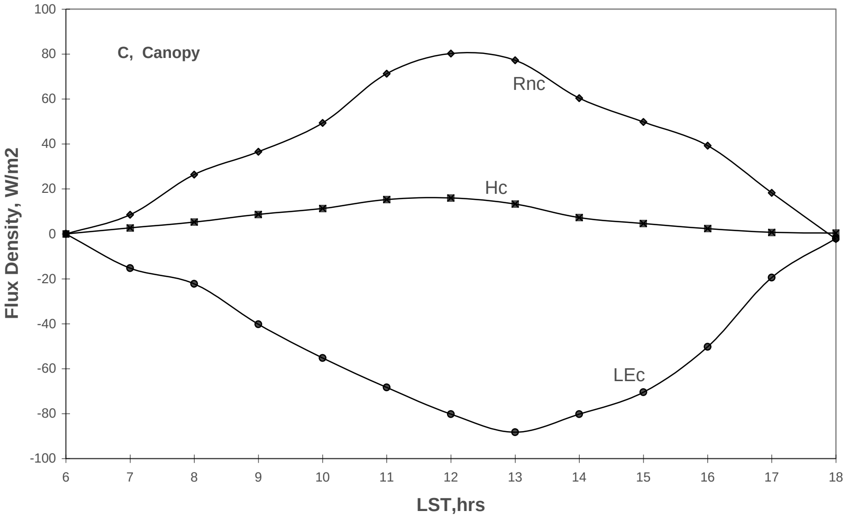
The myriad of surfaces present in the canopy layer make it impossible to draw generalizations. Every surface facet has a unique combination of both its intrinsic properties: irradiative, thermal, moisture and aerodynamic, and those contributed by the rest of the surrounding site environment: radiation geometry, position in flow field, adjacency to almost limitless array of energy balances and therefore microclimates.

Any attempt to produce a climatic classification of these surface units would have to recognize moisture status (water storage capacity and surface moisture availability) to be the primary criterion. Storage capacity is important in that water retention provides a buffering or moderating influence, because gradual moisture depletion allows for evaporative cooling to extend over a period of days or more. On the other hand, impervious elements of the urban landscape experience almost dichotomous wet/dry behaviour, wherein the climatic effects of rain or irrigation may be present for only a few hours before run-off and evaporation dry the surface.

A surprisingly large proportion of the surface area of central parks in the region is occupied by vegetation (30-45%). These surfaces are likely to have water storage capacities equal to those of rural areas and many of them are irrigated in summer from the River Tigris (depending on climate, abundance of water supply and local custom), making water easily available to the atmosphere. Thus irrigated vast parks, lie at one end of the wide spectrum of urban surface types an example of an energy balance is for just such a surface (an irrigated suburban lawn). The pattern is somewhat similar to that of the moist rural surface.

Evapotranspirative losses exceed even the potential rate by about 30% on a daily basis. Probably this is made possible by the advection of warmer, drier air from surrounding impervious surfaces. They act as additional sources of sensible heat capable of forcing the lawn evaporation at a rate in excess of that supportable by (Rn* - RnG). Such. an 'oasis'-type condition can persist only if the natural water budget is supplemented by irrigation.





VI. Conclusions

Trees can affect on mitigating the urban heat island. Because the urban heat island is largely a night-time phenomenon, while trees help lower day-time air temperatures by shielding incoming solar radiation, extensive tree cover also inhibits re-radiation and heat loss at night, keeping surface temperatures high. Results indicate that the radiation balance of the soil and canopy do not describe the soil and canopy latent heat flux during the period of partial cover. During the summer dry soil conditions, LEc can be enhanced by absorption of H from the soil and equilibrium bounder layer. Soil moisture conditions caused convective and radiative transfer within the system and impact on partitioned energy. Canopy latent heat was reduced in wet soil surface by acting as sink for adjective energy, while also reducing the radiation load on the canopy. Soil evaporation was reduced by dry surface condition. However, within the row advection LEc did increased however, during this period difference in total LE from the wet and dry soil can not be a significant.

VII. List of symbols

The following symbols are used in this paper:

Rs	Total global solar radiation,Wm^{-2}
RsI	Solar radiation interception,Wm^{-2}
Rn	Net radiation, Wm^{-2}
Rns	Soil net radiation,Wm^{-2}
Rnc	Canopy net radiation, Wm^{-2}
LE	Latent heat flux density, Wm^{-2}
LE s	Soil latent heat flux density, Wm^{-2}
LE c	Canopy latent heat flux density,Wm^{-2}
H	Sensible heat flux density, Wm^{-2}
Hs	Soil sensible heat flux density, Wm^{-2}
Hc	Canopy heat flux density, Wm^{-2}
G	Soil heat flux density, Wm^{-2}
Cg	Soil specific heat, cal $g^{-2}C^{-1}$
ρ	Soil bulk density, gm cm^{-3}
θ	Soil moisture content, $cm^{-3}cm^{-3}$
ΔT	Soil temperature changes, ^{o}C
Δt	Time changes, min
Δz	Soil depth changes, cm
β	Bowen ratio(dimensionless)
LAI	Leaf area index, $m^{-2}m$

References

[1]. Sailor, D.J.,1998, "Simulations of annual degree day impacts of urban vegetative augmentation", Atmospheric Environment, 43-52.
[2]. Goward, S.N., G.D. Cruickshanks, and A.S. Hope,1985, "Observed relation between thermal emission and reflected spectral radiance of a complex vegetated landscape".
[3]. Remote Sensing of the Environment, 18, 137 – 146.
[4]. Nowak, D., Rowntree, R., McPherson, G., Sisinni, S., Kerkmann, E., Stevens, 1996, "Measuring and analysing urban tree cover", Landscape and Urban Planning, 36, 49-57.
[5]. Lascano, R. J., CH.M. van Bavel, J.L. Hatfielf, and O.R. Upchurch, 1987. Energy and water balance of a sparee crop: Simulated and measuted soil and crop evaporation. Soil Sci. Soc. Am. J. 51:1113-1121.
[6]. National Research Council (NRC) 1991, "Rethinking the ozone problem in urban and regional air pollution", National Academy Press, Washington, D.C. 500 pages.
[7]. Emmanuel, R., 2001, "Summer time urban heat island mitigation: Propositions based on an investigation of intra-urban air temperature variations", Architectural Science Review, 40 (4), 155-164.
[8]. Begg, J.E., J.F Bierhuizen, E. R. Lemon, D.K. Misra, R.O. Slatye and W.R. Stern, 1984. Diurnal energy and water exchange in bulrush millet in an area of high solar radiation. Agri. Meteorol. 1:294-312.
[9]. Brown, K.W., and C. Covey. 1986. The energy - budget evaluance of the microclimatologcal transfer processes within a cornfield. Agri. Meteorol. 3:73-96.
[10]. Kanemasu, E.T., and G.F. Arkin, 1974. Radiant energy and light environment of crops.Agric. Meteorol. 14:211-225.
[11]. Hanks, R.J., L.H., Allen and H.R. Gardener, 1981, "Advection and evapotranspiration of wid e-row sorghum with central great plain", Agron. J. 63:520-527.
[12]. Chin Choy, E.W. and E.T. Kanemasu, 1994, "Energy ballance comperasions of wide and narrow row spacing in sorghum", Agron. J. 66:98-100.
[13]. Fuchs, M. 1992, "The control of the radiation climate of plant communities", P. 173-197. In D. Hillel(ed) optimizing the soil physical environment toward greater crop yield. Academic Press, New York, N.Y.
[14]. Fuchs, M. and C.B. Tanner. 1966, "Infrared thermometry of vegetation", Agron. J. 58: 597-601.
[15]. Fuchs, M. and Tanner, C.B. 1970. Error analysis of Bowen ratio measured by Differential psychrometery. Agri. Meteorol. 7:329-334.
[16]. Hasson, A., 2008, "Atmospheric Dust Properties and Its Effect on Light Transmission and Crop-Soil Productivity", Journal of Agriculture, Food and environment, 2,1,1-12.
[17]. Tanner, C.B., 1960. Energy balance approach to evapotranspiration from crops. Soil Sci. Soc. Am. Proc. 24:1-9.
[18]. Fuchs, M; and A. Hadas, 1973. Analysis of the performance of an improperd Soil heat flux. Water Soil Sci. Soc. Am. Proc. 37: 173-175.
[19]. Ritchie, J.T. 1971. Dryland evaporation flux in a subhumid climate: Microclimatological influences. Agron. J. 63:51-55.
[20]. Ham, J.M. JL. Heilman, and R.J. Lascano, 1999. Determination of soil waterevaporation, and transpiration from energy balance and stem flow measurements. Agric. For. Meteorol. 52:287-301.
[21].Fritschen, L.H., 1974. Constraction and calculation of a miniature net radiation. Appl. Meteorol. 2:165-172.
[22]. Fritschen, L.H. 1984. Miniature net radiometer. J. Appl. Meteorol. 1:528-533, Univ. Press. Cambridge,N.J.
[23]. Sakuratani, T. 1997. Studies on evapotranspiration crops (2) separate estimation transpiration and evaporation from soybean field without water storage. J. Agric. Metearol. 42:309-317.
[24]. Shuttleworth, J.W. and J.S. Wallance. 1985. Evapotion from spares crops on energy commbination theory. Meteorol. J. 111:839-855.
[25]. Sargent, D.H., & C.B. Tanner. 1977, "A simple psychrometer approachs for Bowen ratio determination", J. Appl. Meteorol, 414-418.

List of Figures and Tables