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Variation of residual energy fluxes in relation to plant height and biomass in groundnut

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ABSTRACT

Radiation and Energy Budgets over a cropped surface have been studied under the Land Surface Processes Experiment (LASPEX-97) conducted in the Sabarmati river basin, at Anand, Gujarat. Continuous data on temperature, humidity, wind speed and direction recorded at 1 and 4 m on 9 m tower over the cropped surface during the period of March 1997 to August 1997 is used. Soil heat flux is calculated by conductivity method. Sensible and latent heat fluxes are calculated by three different methods viz. Aerodynamic, Bowen's Ratio and Eddy Correlation. Variation of residual flux during the months of March, April, May, July and August '97 is studied in relation to biomass and crop height. AE/PE is parameterised with pan evaporation for three consecutive months July, August and September 1997.

Key words : Radiation balance, Residual energy, Aerodynamic, Bowen ratio, Eddy correlation

Surface boundary layer is the lowest layer of the atmosphere through which the exchange of heat, water vapour and momentum takes place between the earth's surface and the overlying atmosphere. The source of energy for all these atmospheric processes including the biological activities is the Sun. The solar radiation during its travel from the sun to earth through the atmosphere undergoes scattering, absorption, reflection etc. and ultimately reaches the ground surface. The resultant between incoming total radiation and outgoing radiation at the earth-atmosphere interface is the net radiation. Where there is no advection of energy this net radiant energy is apportioned to partly for heating the air, partly for evaporating water and the remainder for heating the soil. Where the soil is covered with vegetation, the same net radiation is also partly utilised for transpiration and photosynthesis.

Radiation balance

As already stated the difference between total upward & downward radiative fluxes forms the radiation balance written as

$$Q^* = S + L$$

where, S and L are the short wave and long wave radiation balance terms which can be further expressed as

$$S = S\downarrow - S\uparrow$$
$$L = L\downarrow - L\uparrow$$

hence, $$Q^* = S\downarrow - S\uparrow + L\downarrow - L\uparrow$$

The downward and upward arrows denote incoming and outgoing radiation respectively. For a given surface, if it is opaque to short wave radiation, the net short wave radiation is expressed by the relation

$$S^* = (1 - (\alpha) S$$

and is determined by insolation at the ground and albedo of the surface.

Energy budget over vegetation

If the energy fluxes are directed into and away from a surface without any loss or gain due to the surface, then the principle of conservation of energy at the surface can be expressed as

$$Q^* = Q_H + Q_E + Q_G$$

where,

Q^* = net radiation

Q_H = sensible heat flux

Q_E = latent heat flux

Q_G = ground heat flux

When the terms on the R.H.S of the energy balance equation are positive, they represent losses of heat from the surface and when they are negative, they are deemed as gains from sub-surface and atmospheric sources.

In case of the vegetated surface, the energy balance equation (Monteith, 1976) can be written as

$$Q^* = Q_H + Q_E + Q_G + \Delta Q_S + \Delta Q_P$$

where, ΔQ_S is the net rate of physical heat storage in the system, resulting from the absorption or release of heat by the air, soil and plant biomass (leaves, branches, stems etc.). For bare soil or short bending crops this reduces to Q_G. ΔQ_P is the residual flux which is supposed to be used by the plants for photosynthesis. This residual flux, ΔQ_P, is linked to the rate of assimilation by the plants.

There is an interaction between cropped surface and the complex system of environmental conditions, where meteorological factors are the most variable and active. They largely determine the crop yields and the yield quality. In the present study, the effect of radiation on a cropped surface viz relationship between the growth of plants and the amount of residual flux utilised by them under different phenological phases is examined using three different methods of energy budget computations.

MATERIALS AND METHODS

The data utilised in this study is the part of the data collected during the Intensive Observational Period (IOP) of March 1997 to August 1997 in LASPEX -97. Continuous data recorded on a 8 m tower over cropped surface at Anand, Gujarat is used.

Soil heat flux

For a thin layer of soil of thickness $\Delta z'$, neglecting any horizontal conduction of heat in the soil, the rate of change of soil temperature is given by

$$\rho_s c_s (\partial T_s / \partial t) = - (\partial Q_G / \partial z') \quad ....(1)$$

where,

ρ_s = soil density

T_s = soil temperature

c_s = sp. heat of soil

z' = the vertical co-ordinate (+ve down) into the soil

The subsurface heat flux Q_g at any level z' can be described by Fourier law for heat conduction in a homogeneous body (van Wijk and De Vries, 1965; Fritschen and Gay, 1979)

$$Q_G = - K_s (\partial T_s / (\partial z')$$

where $K_s = k_s \rho_s c_s$ and
k_s = thermal diffusivity

Sensible heat flux and latent/evaporative heat flux

a. Aerodynamic method

Sensible (Q_H) and latent heat fluxes (Q_E) are calculated by

$$Q_H = - \rho C_p k^2 z^2 \left(\frac{\overline{\Delta u}}{\Delta z} \cdot \frac{\Delta T}{\Delta z} \right) \quad ...(2)$$

$$Q_E = - \rho L_v k^2 z^2 \left(\frac{\Delta u}{\Delta z} \cdot \frac{\Delta q}{\Delta z} \right) \quad ...(3)$$

These are the neutral stability aerodynamic equations (Oke,1987). The generalised forms of these equations are

$$Q_H = - \frac{\rho C_p k^2 u (T - Ts)}{\{ \ln (z/z_o) + \varnothing_M \} \{ \ln (z/z_h) + \varnothing_H \}} \quad .....(4)$$

$\varnothing_M$, $\varnothing_H$, $\varnothing_W$ are dimensionless stability functions to account for curvature of the logarithmic wind profile (neutral stability condition) due to buoyancy effects, heat and water vapour and

$\varnothing_H = \varnothing_W = \varnothing_M$ in moderately stable conditions

$\varnothing_H = \varnothing_W = \varnothing_M^2$ in unstable conditions

$\varnothing_M = 1.47\ z/L$ for $z/L > 0$ (stable)

$\varnothing_M = 1.0$ for $z/L = 0$ (neutral)

$\varnothing_M = (1-15\ Z/L)-1/4$ for $z/L < 0$ (unstable)

$$z/L = \frac{g\, k\, z\, Q_o}{T \rho\, Cp\, u_*} \text{ or}$$

$$Ri = \frac{g}{T} \frac{(\Delta T / \Delta z)}{(\Delta u / \Delta z)}$$

Z_o and Z_h are roughness lengths for wind and temperature.

$$Q_E = - \frac{S(Q^* - Q_g) + \rho C_p ed / ra}{S + \gamma (1 + r_s / r_a)} \quad .....(5)$$

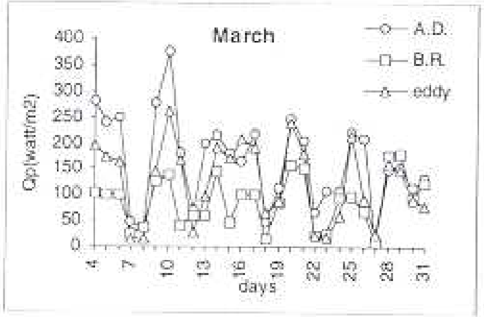
where
S = slope of saturated vapour pressure curve
e_d = vapour pressure deficit of air
γ = psychrometric constant
r_s = surface resistance (sm^{-1})
r_a = aerodynamic resistance (sm^{-1})

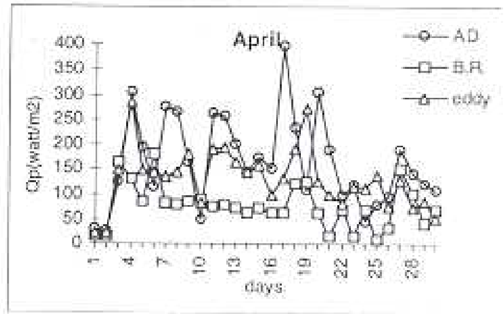
b. Bowen's ratio method

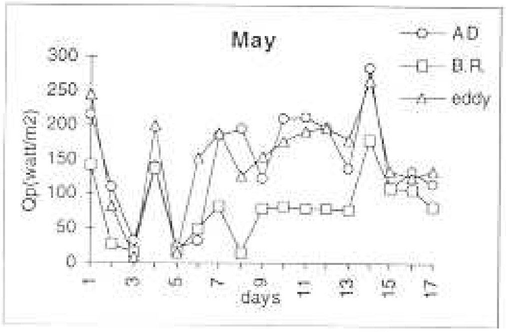
The energy balance approach to estimating convective fluxes seeks to apportion the energy available ($Q^* - Q_G$, or $Q^* - \Delta Q_S$) between the sensible and latent heat terms by considering their ratio, β. This method has the advantage of not being stability - limited because it only requires similarity between K_H and K_W and not K_M (Oke, 1987)

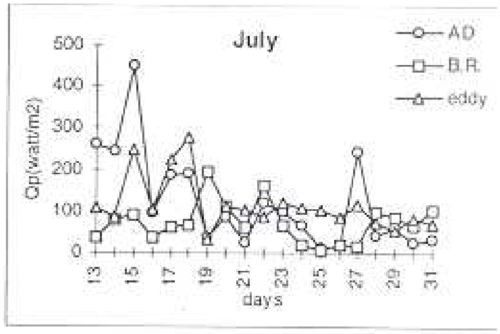
$$Q_H = \frac{\beta (Q^* - Q_G)}{1 + \beta} \quad ......(6)$$

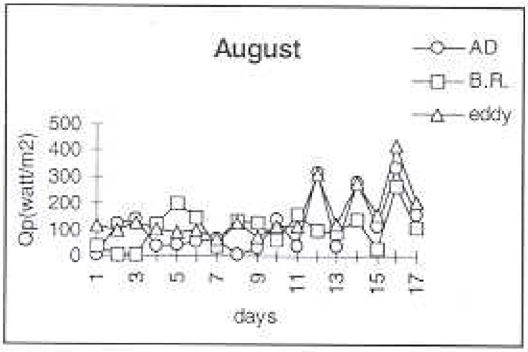
$$\beta = \frac{Q_H}{Q_E} = \frac{C_p \Delta T}{Lv \Delta_q}$$











AD = Aerodynamic method.
Qp = Residual flux
B.R. = Bowen's Ratio method,
eddy = Eddy Correlation method
Days are reckoned from date of sowing

Fig. 1 : Variation of residual flux in different months

$$Q_E = \frac{Q^* - Q_G}{1 + \beta} \qquad ......(7)$$

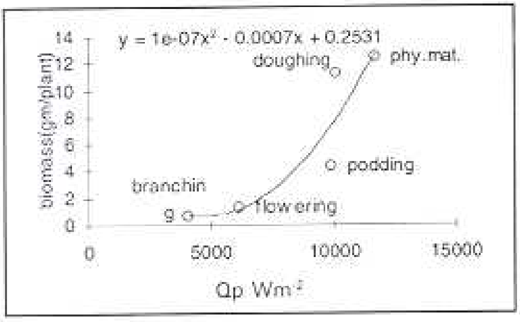
Eddy correlation method

Eddy correlation method (Oke, 1987) was used for computing the heat and water vapour fluxes Q_H and Q_E respectively.

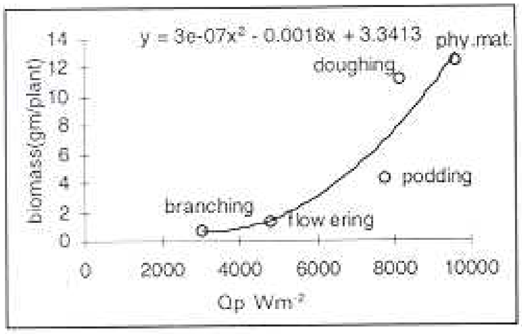
where

$$Q_H = \rho C_p \overline{w'q'}$$

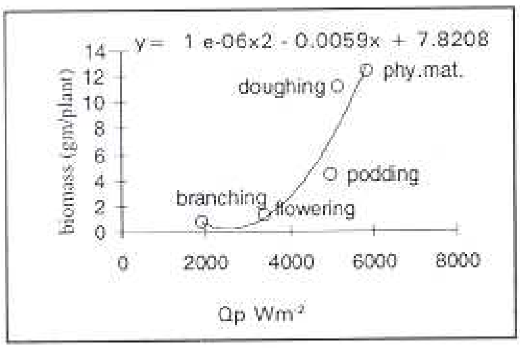
$$Q_E = \frac{\rho \lambda \epsilon}{p} \overline{w'q'}$$



Aerodynamic method

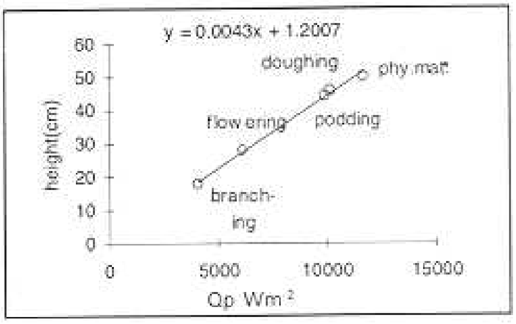


Bowen's ratio method

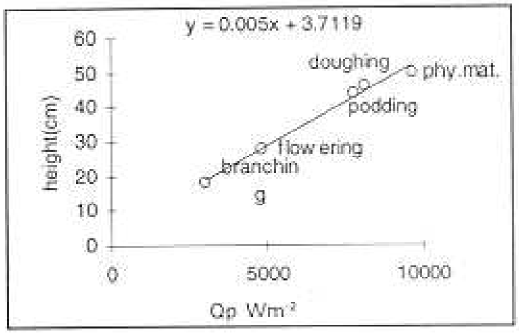


Eddy correlation method

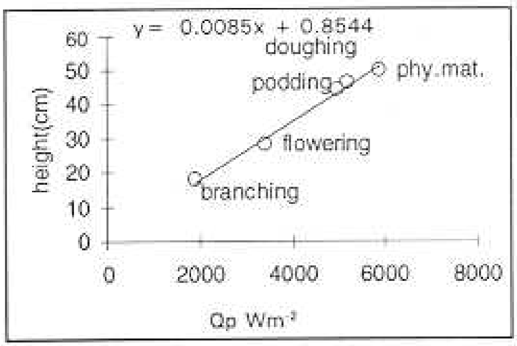
Fig. 2 : Residual flux and biomass of groundnut



Aerodynamic method

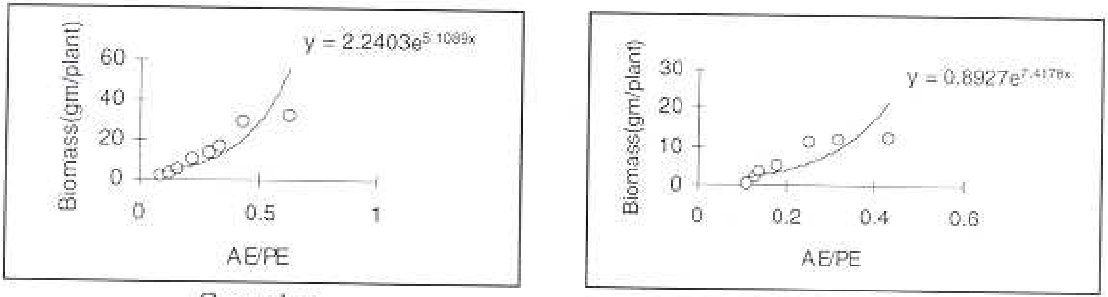


Bowen's ratio method



Eddy correlation method

Fig. 3 Residual flux and height of groundnut



Groundnut Greengram

Fig. 4 : Relationship between AE/PE and biomass of groundnut and green gram

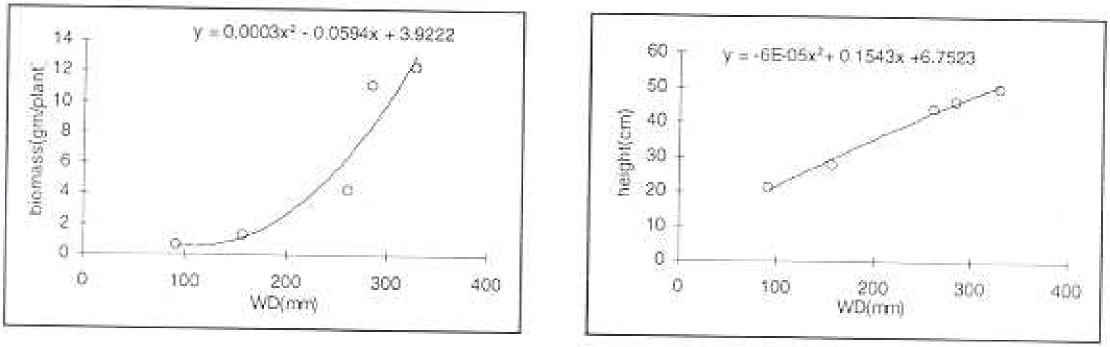


Fig. 5 : Relationship between water deficit vs biomass and height of the crop (groundnut)

λ = latent heat of vaporisation
ϵ = ratio of molecular weights of water vapour and dry air (0.662)
p = air pressure

Computation of water balance

Direct measurements of precipitation (P), actual evapotranspiration (AE) with lysimeter, potential evapotranspiration (PE) by Penman's method are used to calculate the water surplus (WS) and water deficit (WD) by the book keeping procedure of Thorthwaite (Thorthwaite and Mather, 1955). Penman's method as described by Doorenboss and Pruitt (1975) has been used for computing potential evapotranspiration in mm H_2O day^{-1}.

RESULTS AND DISCUSSION

Variation of residual flux

Fig. 1 shows the variation of residual flux during the months of March, April, May, July and August-97 calculated by three different methods namely aerodynamic, Bowen's ratio and eddy correlation. Of these three, aerodynamic method gives the highest values and Bowen's ratio method the least residual flux in each month.

Residual flux and biomass

Fig. 2 shows the polynomial relationship between residual flux and thebiomass under

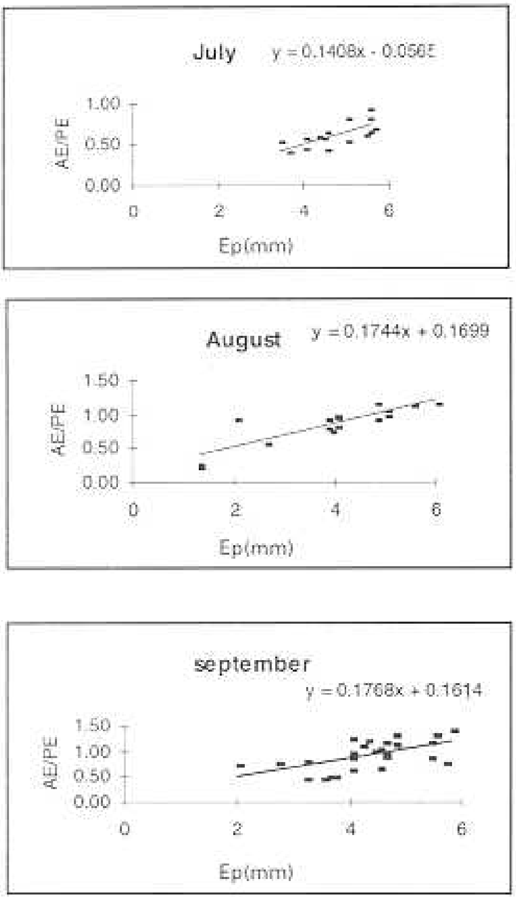


Fig. 6 : Parameterization of AE/PE with Pan evaporation (Ep) for the month of July, August and September-97

different phenological phases of the crop. The aerodynamic method gives the correlation coefficient of 0.843, Bowen's method 0.862 and Eddy Correlation method 0.833 at 0.05 level of significance.

Residual flux and plant characteristics

Linear relationship is found between residual flux and plant height under different phenological phases of the plant (Fig.3). The correlation coefficients are 0.997 (Aerodynamic method), 0.993 (Bowen's ratio method) and 0.998 (Eddy correlation method) at 0.05 level of significance.

Relationship between AE/PE versus biomass in two crops

Relationship between AE/PE and biomass for groundnut and greengram are shown in Fig. 4. The biomass of the crops increases exponentially with the increasing AE/PE ratio. Greater the AE/PE ratio, greater will be the transpiration and more will be the biomass. The correlation coefficients are 0.973 and 0.919 respectively at 0.05 level of significance.

Water deficit versus biomass and plant height

Fig. 5 shows the relationship between the Water deficit and the biomass and height. In both the cases, the relationship shows the polynomial trend with correlation coefficient of 0.995 & 0.901 respectively at 0.05 level of significance.

Parameterization of AE/PE

AE/PE is parameterised with pan evaporation (Ep) for the three consecutive months July, August and September, which shows a linear relationship for each month (Fig. 6). The correlation coefficients for July, August and September-97 are 0.698, 0.871 and 0.584 respectively at 0.05 level of significance.

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