# Soil Heat Flux - Net Radiation Relations for some Surfaces

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## Abstract

Accurate estimates of the net radiation, $R_n$, and the soil heat flux, $Q_g$, are important for many studies involving the surface energy balance. In particular, the difference between them is the primary term for the determination of evapotranspiration. The paper reports the net radiation and soil heat flux measured for two areas, Legon and Dawhenya in the Greater Accra Region. The purpose was to use them in determining latent heat and sensible heat fluxes. The results are shown for October 1994 and August 1995 for Legon, and April 1996 for Dawhenya. The soil heat flux showed good correlation with net radiation. Gradients of soil heat flux and net radiation plots ranged between 0.2 and 0.45 for short grass (1994), and between 0.16 to 0.22 for corn (1995) at Legon. At Dawhwenya, it showed values between 0.19 and 0.27 (1996). Gradients for the regression lines agree with reported ratios of $Q_g$ to $R_n$.

## Introduction

Net radiation, ($R_n$), and soil heat flux, ($Q_g$) are two most important components of the Earth's surface energy balance. This is because the difference between them is the primary term for the formulations for evapotranspiration (Davies, 1971; Idso *et al*., 1975; Dugas *et al*., 1991). The soil derives its heat almost entirely from the Sun and loses much of it by radiation into the sky (Payne & Gregory, 1968). The absorbed radiation is dissipated in four different ways: re-radiation to the sky, latent heat of evaporation of soil water, increase in temperature of the surface soil and through conduction. A very small amount is absorbed by green plants for photosynthetic activities. The surface energy balance is given by the relation

$$R_n = Q_g + Q_e + Q_h + Q_{PS} + Q_m \qquad (1)$$

where $Q_e$ is the latent heat flux and $Q_h$ is the sensible heat flux $Q_{PS}$ is the flux due to photosynthesis and $Q_m$ is due to miscellaneous energy changes. Thus, any approach at determining the partition between evaporation and sensible heat flux depends on the proper evaluation of the difference between the net radiation and the soil heat flux, ($R_n - Q_g$), assuming photosynthetic conversion and other miscellaneous energy changes are negligible.

The importance of the accurate estimates of the soil heat flux is that it is used in many studies involving the surface energy balance. Some examples are the use along with the other components of the surface energy balance to infer properties of vegetation canopies (Hatfield, 1985) for verification of eddy correlation approach to flux measurements (Massman *et al.*, 1990), and for the verification of biosphere parameterization in large scale models (Sellers *et al.*, 1986). Massman (1992) discussed an error which can arise when measuring soil heat flux by the combination approach and outlined a method to correct it. The combination method, developed by Fuchs & Tanner (1968), estimates the soil heat flux by measuring the heat flux at a depth, z, below the surface and adding on to it the heat storage in the overlying soil layer.

The ground heat flux is obtained from the expression:

$$Q_g = k\frac{dT}{dz} + \rho C\frac{dT}{dt} \qquad (2)$$

where k is the thermal conductivity, ρ is the density and C is the specific heat of the soil. The first term on the right is the flux component and the second term is the storage component (Reimer & Desmarais, 1973; Payne & Gregory, 1988).

The thermal conductivity of the soil is very dependent on its air and water content. A more compact soil with high water content has greater thermal conductivity and, hence, more heat conduction. Vegetation also has effect on soil temperature since it intercepts part of the incoming and back radiation from the soil. The degree depends on the extent to which the leaves shade the soil surface from the sky. Under vegetation, the soil will warm up or cool down more slowly. Vegetation effect on the heat flux into and out of a soil depends on the thickness and height of its canopy.

In this paper, results of correlation between soil heat flux and net radiation, measured over short grass and corn, are presented. The data presented are for short grass in October 1994, for corn in August 1995 both at Legon, and for short grass at Dahwenya in April 1996.

## Materials and methods

The experimental farm sites were the farm sites of Faculty of Agriculture, University of Ghana, Legon and the Dawhenya rice irrigation project. Fig. 1 shows the site at Legon and the equipment being set up. The surface at Legon is being prepared for planting and the tractor can be seen in the background. Therefore, the soil is loose with short grass on it.

Fig. 1. Study area at Legon with the equipment being mounted.

At Dawhenya the surface is dry earth with very short grass on it. The equipment was set up in a fenced local weather station operated by the farm authorities. The lake used for irrigation was about 50-100 m away from this site. The primary data were net radiation, soil heat flux and soil temperature. Net radiation was obtained using a net radiometer, mounted at a height normally greater than 2 m. The ground flux was measured using heat flux plates buried in the soil at a depth of 8 cm within a radius of 2 m from a Bowen ratio mast (Fig. 2). The storage term was determined by measuring the change in soil temperatures at depth z in time interval t. The heat capacity of the soil was determined by adding the specific heat of the dry soil to that of the soil water on mass basis, given by:

$$C = B_D(C_s + wC_s) \qquad (3)$$

where $B_D$ is the soil bulk density, $C_s$ is the specific heat capacity of the dry soil, w is the soil water content on mass basis (kg-$H_2O$/kg-soil) and $C_w$ is the specific heat of water. Other measurements made are the soil moisture content and the soil bulk density determined once a week. The soils were collected using gravimetric rings and the samples dried in an oven.

Chromel-constantan thermocouples were used to measure the soil temperature. The probe consists of four thermocouples connected in parallel. These were installed close to each soil heat flux plate at depths of 2 cm and 6 cm and covered gently with soil. All measuring devices were connected to a Campbell Scientific Bowen-ratio system and Campbell data logger model CR-21X for storage of data at 20 min intervals. Details of equipment and acquisition of data are described in Campbell Scientific Bowen Ratio Handbook (1991). The temperature gradient was taken over the last 5 min of each 20-min data storage period.

## Results and discussion

Results of various measurements are shown plotted. Fig. 2 is the diurnal variation of air and soil temperatures. The air temperature is normally lower than the soil temperature and also reaches a peak a few hours before soil temperature does. In Fig. 2(b), soil temperatures are almost equal to the air temperatures. The soil heat flux $Q_g$ and the heat flux plate measurements FX are shown plotted in Fig. 3. The flux as measured by heat flux plates is generally less than or equal to the storage heat at a depth of measurement. Relation between measurements of soil heat flux $Q_g$ and net radiation $R_n$ are shown plotted in Fig. 4-6. The data is plotted as points. In Fig. 4-6 the regressions are the solid lines representing the estimated equation. The results show good correlation between $R_n$ and $Q_g$. The cluster of points around the intercept is due to night values when all fluxes are zero or negative because there is no sunlight.

In Fig. 3, the correlation coefficients are between 0.77 and 0.90. The gradients of $Q_g$ and $R_n$ are between 0.24 and 0.45. Correlations for August 1995 (Fig. 4) are between 0.63 and 0.73, and gradients of the correlation lines range between 0.16 and 0.22. Correlation coefficients are much lower than the values in Fig. 3. The reason for this is that the soil was much more covered by the corn. At this time the corn had grown and covered the soil. Therefore, not much sunlight is penetrating the soil. There had also been some rainy days.

Results for Dawhenya are shown in Fig. 5. The results show correlation coefficients ranging between 0.87 and 0.97 with gradients between 0.19 and 0.27. The correlation is much better because of the almost bare surface. It has been reported that $Q_g$ is generally between 0.3 and 0.6 of $R_n$ in dry bare soil, and between 0.05 and 0.1 for soil covered by vegetation (Gregory, 1988). Using synoptic observations to calculate the energy balance terms, De-Heer-Amissah (1973) has shown that soils with low water holding capacity have higher rates of evapotranspiration, hence inferring that evapotranspiration is controlled not so much by soil water content by itself but by soil water tension.

## Conclusion

Soil heat flux shows linear regression with net radiation with significant correlation coefficients. Regression coefficients for data over corn were lower. This as explained, depends on the degree to which the leaves shade the soil surface from the sky. The gradients agree quite well with the reported ratios of $Q_g$ to $R_n$ for various types of soils (Gregory, 1988).

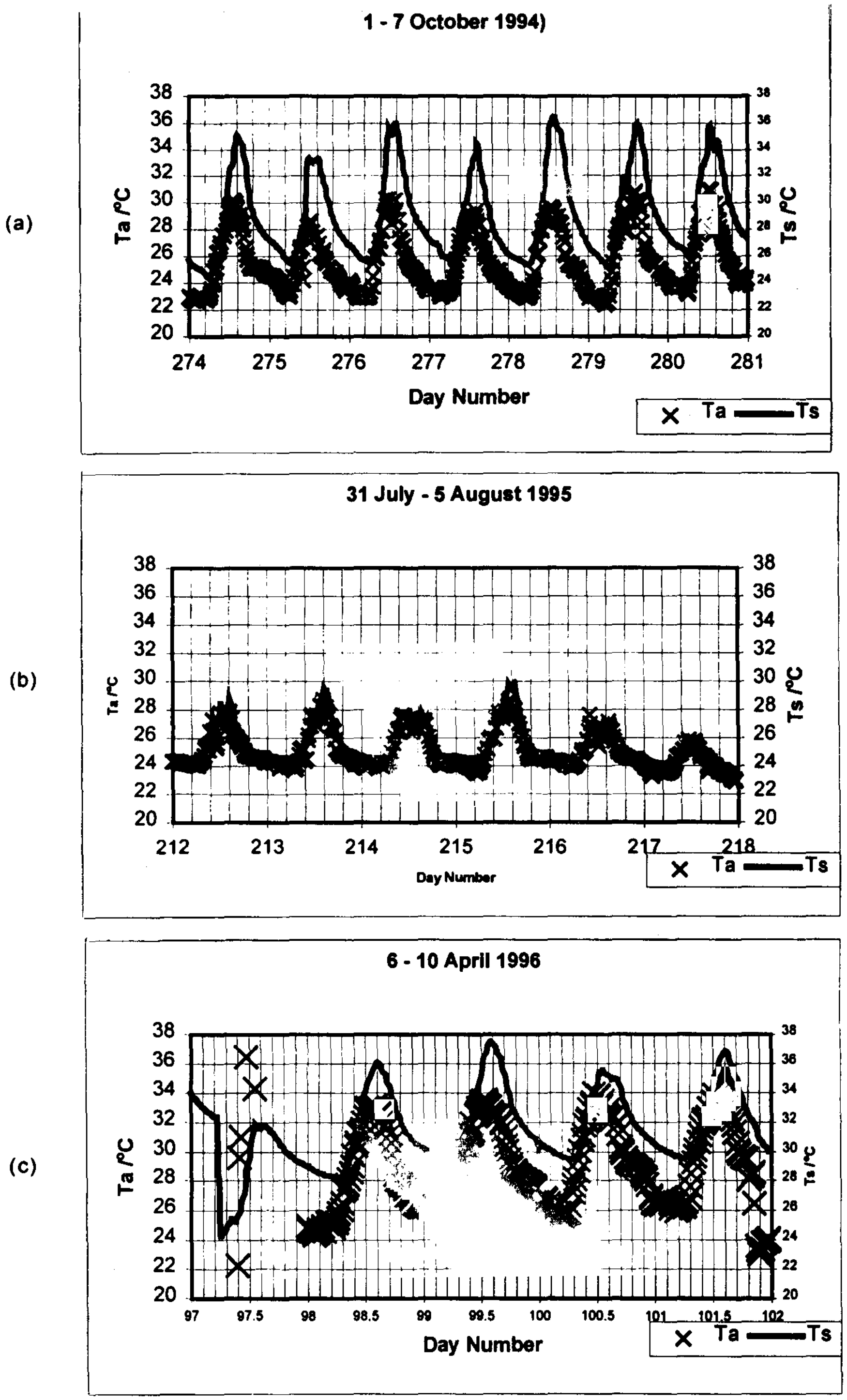


Fig. 2. Air and soil temperatures

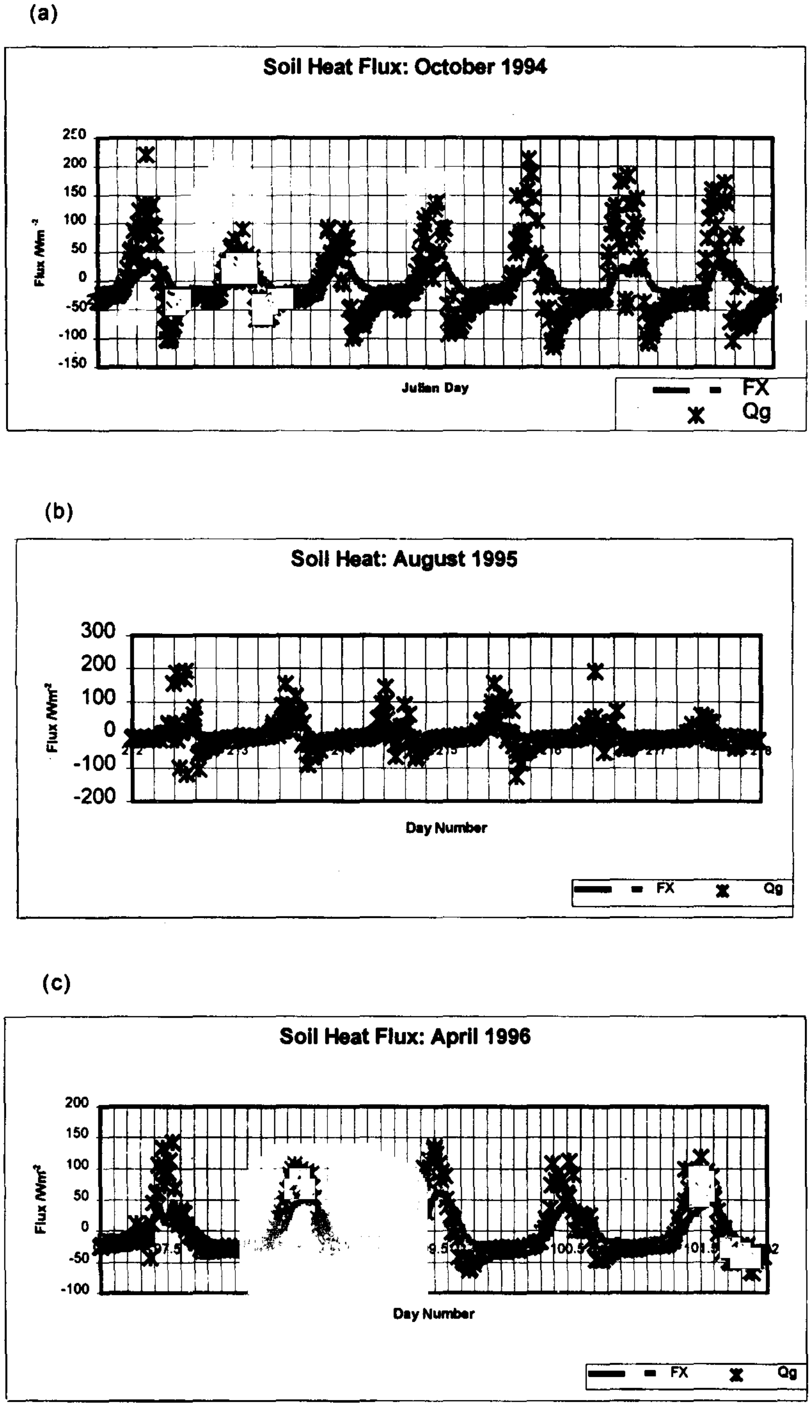
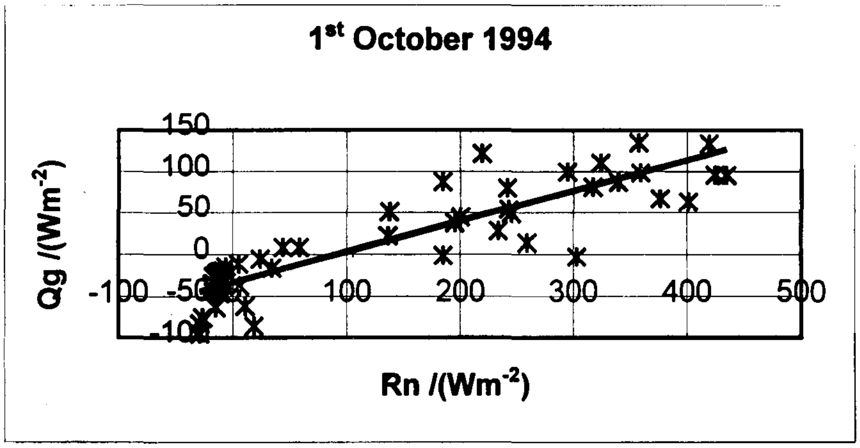
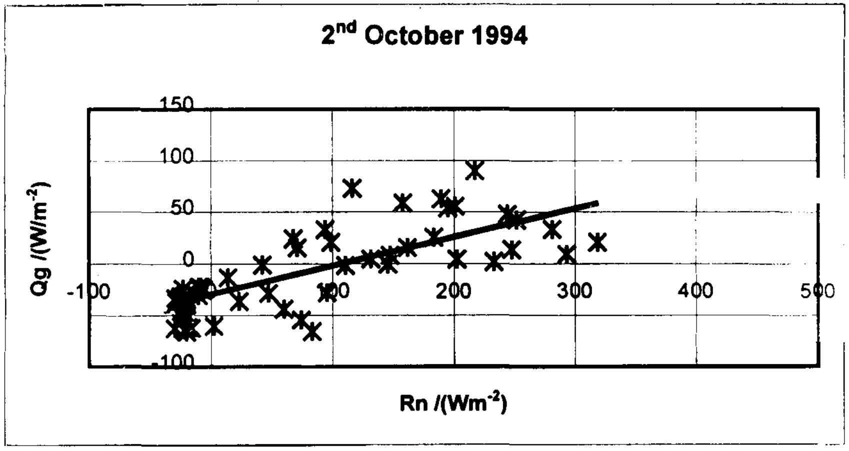


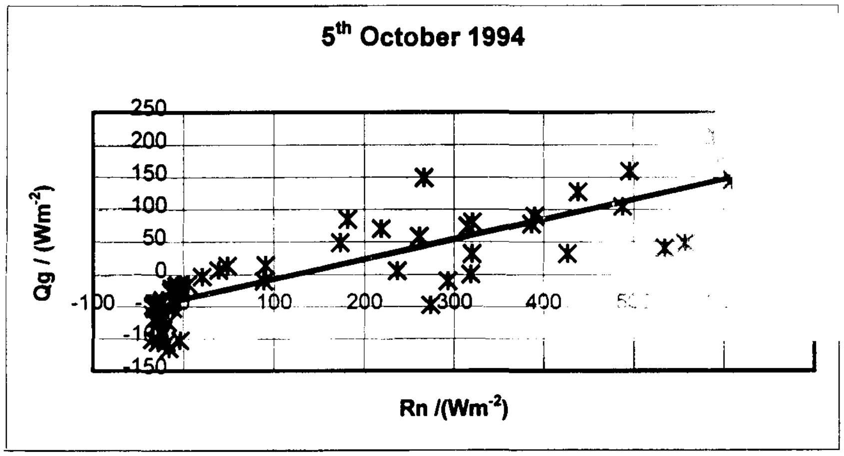
Fig. 3. Soil Heat Flux



y = 0.37x - 34.07; r = 0.87

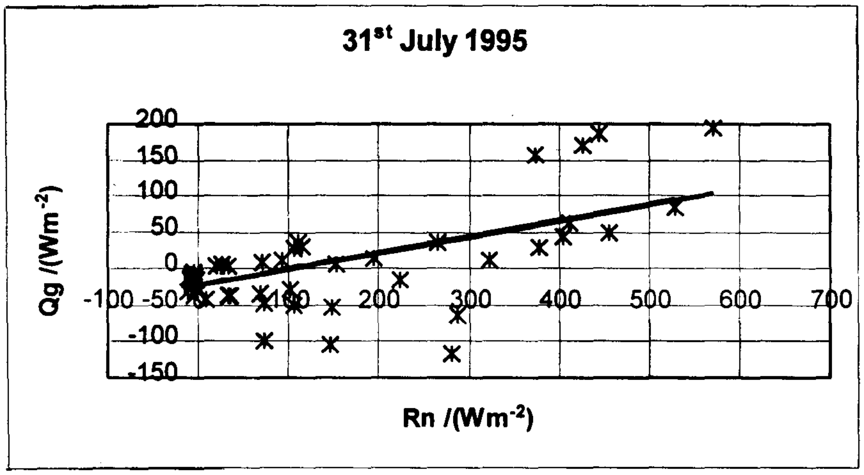


y = 0.28x - 29.55; r = 0.77

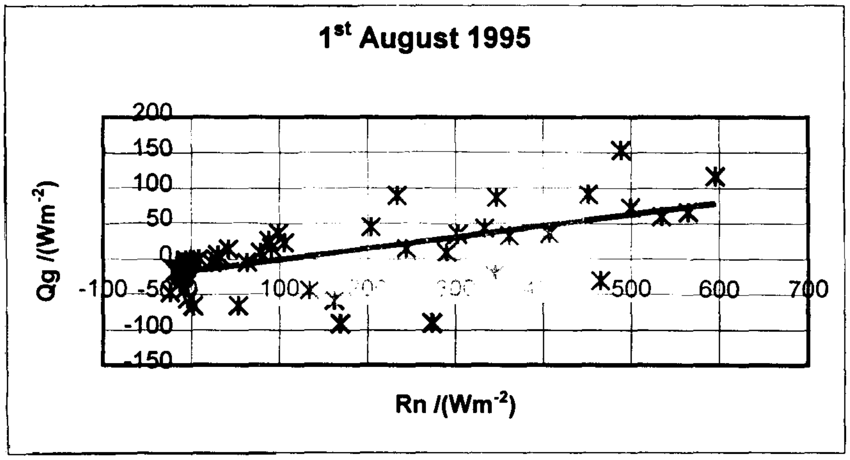


y = 0.31x - 37.96; r = 0.86

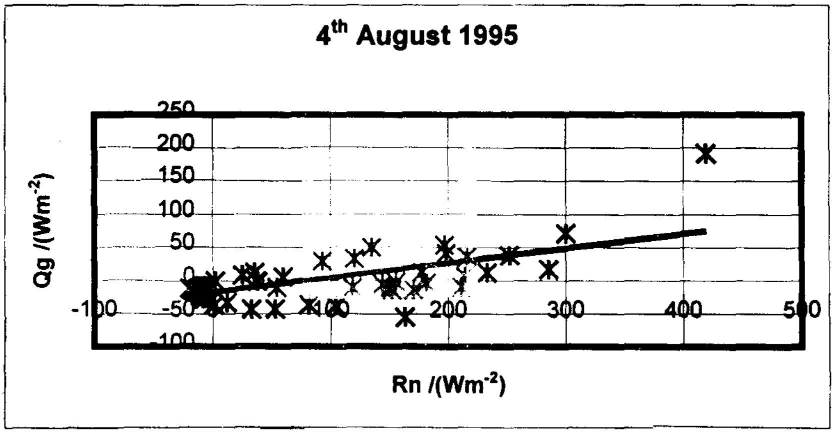
Fig. 4. Qg–Rn relations for October 1994.



y = 0.22x - 22.20; r = 0.64

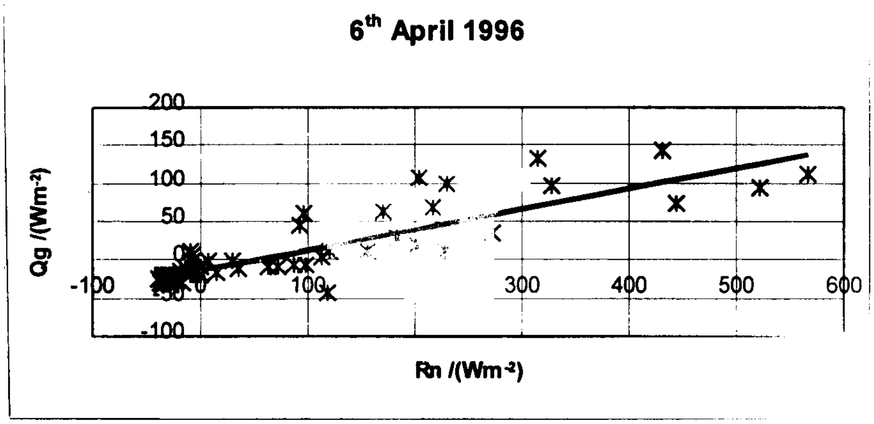


y = 0.16x - 16.48; r = 0.64

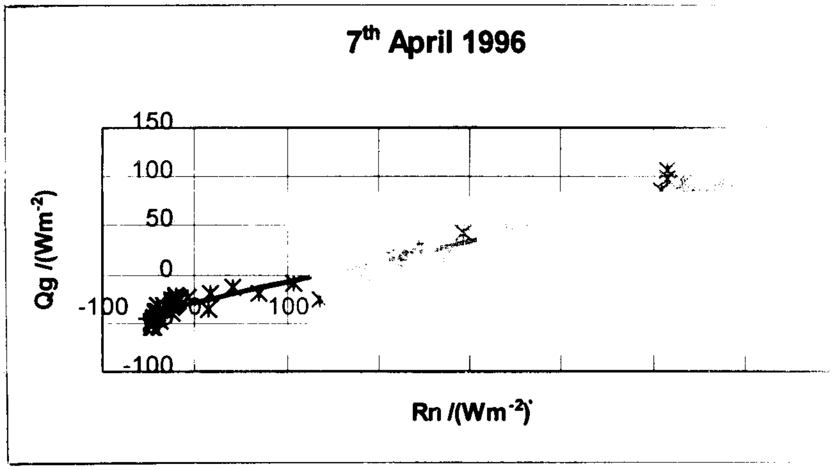


y = 0.22x - 17.07; r = 0.67

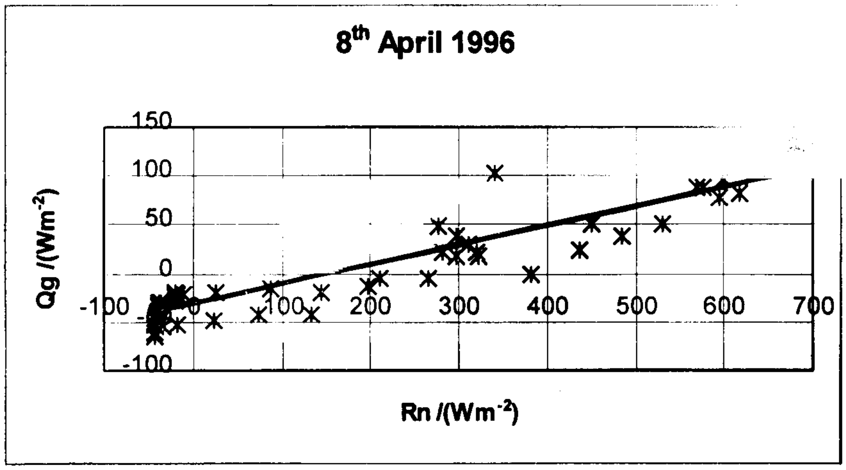
Fig. 5. Qg–Rn relations for August 1995



y = 0.27x - 14.30; r = 0.87



y = 0.21x - 28.38; r = 0.97



y = 0.20x - 29.74; r = 0.94

Fig. 6. Qg–Rn relations for April 1996.

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