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Soil heatflux under coconut (*Cocos nucifera Linn*) in an humid tropical oxisol

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सार — आर्द्र उष्णकटिबन्धीय जलवायु में नारियल के पेड़ के नीचे ऑक्सीसोल के भीतर ताप अभिवाह का विश्लेषण किया गया था।

इस क्षेत्र में शुष्क दिनों (दिसम्बर से मई) में उच्चतम दैनिक सौर विकिरण तथा वायु तापमान पृथक-पृथक 1050 डब्ल्यू एम$^{-2}$ तथा 35° सेल्शियस तक जाता है। ग्रीष्म ऋतु में एक दिन खुले मैदान में अधिकतम सतह मृदा तापमान (2.5 सेंटीमीटर की गहराई तक) 62° सेल्शियस पाया गया। खुले मैदान में 5 सेन्टीमीटर की गहराई तक मृदा तापमान का दैनिक परिवर्तन 33° सेल्शियस से 45° सेल्शियस के बीच था तथा नारियल छत्र के कारण 2° से 7° सेल्शियस तथा प्राकृतिक मलवार सामग्री के कारण 1° से 7° सेल्शियस तक कम हो गया था।

पी डब्ल्यू पी (स्थाई म्लान बिन्दु) आर्द्रता पर मृदा की ताप क्षमता 0.4315 कैलो०/से०मी०^{2}/° सेल्शियस तथा विसरण मान 0.596 10^{-3} से०मी०$^{-2}$ सैकिण्ड$^{-1}$ थे। नारियल के बाग में मृदा की 5 से 10 सें०मी० परत के नीचे दैनिक ताप अभिवाह +0.412 तथा –0.165 कैलो/से.मी.^{2}/घंटा के बीच था। जबकि नारियल के बाग में इसका परिसर +0.494 और –0.296 कैलो. सें.मी.$^{-2}$/घंटा के बीच था। 2.5 से 5.0 सें.मी. गहराई के भीतर अधिकतम सतह ताप अभिवाह 6.42 कैलो./सें०मी०^{2}/घंटा था। नारियल के पेड़ की जड़ के आसपास मलवार ताप प्रवाह के संतुलित अथवा ऋणात्मक कर देता है।

विभिन्न ऋतुओं में 1430 बजे भा.मा.स. में 5-10 सें.मी. के बीच अधिकतम ताप प्रवाह 0.849 कैलो. सं.मी.$^{-2}$/घंटा तक था तथा यह मृदा आर्द्र मात्रा से सम्बन्धित न था।

ABSTRACT. The heatflux into an oxisol under coconut in an humid tropical climate was analysed.

The peak daily solar radiation and air temperature during dry period (December-May) in this region goes upto 1050 Wm^{-2} and 35° C respectively. The maximum surface soil (2.5 cm depth) temperature observed in an open field was 62° C on a summer day. The diurnal variation of soil temperature in the open field was between 33° and 45°C at 5 cm depth and it was reduced by 2-7° C due to coconut canopy and by 1-7° C due to natural mulch material.

The heat capacity and diffusivity values of the soil were 0.4315 cal cm^{-2} °C^{-1} and 0.596 x 10^{-3}cm^{-2}sec^{-1} respectively at PWP (permanent wilting point) moisture content. The diurnal heatflux into 5-10 cm layer of soil was between +0.412 and —0.165 cal cm^{-2} hr^{-1} in the open field, whereas it ranges between +0.494 and —0.296 cal cm^{-2} hr^{-1} in the coconut garden. The maximum surface heatflux into 2.5-5.0 cm depth was 6.42 cal cm^{-2} hr^{-1}.

Mulching around the basin of the coconut tree causes heatflow to be either at equilibrium or negative.

The maximum heatflow into 5-10 cm layer (1430 IST) was upto 0.849 cal cm^{-2} hr^{-1} in different seasons and it is not related to soil moisture content.

1. Introduction

Soil heatflux under a given crop refers to the net energy available which will be utilised either for evaporation or lost to the surrounding atmosphere as sensible heat. The soil profile temperatures and heatflux may also influence the pattern of moisture distribution in soil (Rosenberg 1974) and the heatflux at various depths can give a good indication of the evaporating zone (Gardener and Hanks 1966). Such studies will be useful in coconut plantations of humid tropical Kerala (latitudes 8° 17′-12° 47′ N; longitudes 74° 51′-77° 24′E) where soil temperatures below the canopy were observed to be as high as 45° C at 5 cm depth (Varadan and Rao 1983) and prevails for prolonged period during December to May. Quantification of soil heatflow in these areas will further help to understand the energy balance and optimisation of thermal regime both under coconut and intercrops between them.

The soil heatflux depends upon insolation, thermal properties of the soil such as heat capacity and diffusivity and on the moisture content of the soil. It can be either directly measured using a soil heatflux plate (Fuchs and Tanner 1968) or indirectly computed from the temperature gradients and thermal properties of the soil (Johnson and Davies 1927). Studies on heatflux into the soil have been reported by several workers (Murthy and Subrahmanyam 1961; Subrahmanyam and Ratnam 1970 etc).

The present paper analyses the heatflux variations in a coconut grown oxisols.

2. Materials and methodology

(a) *Field observations*

The experiment was located in the campus of the centre at Kottamparamba (Latitude 11° 15′N, Longitude 75° 52′E and altitude 70 m above m.s.l.).

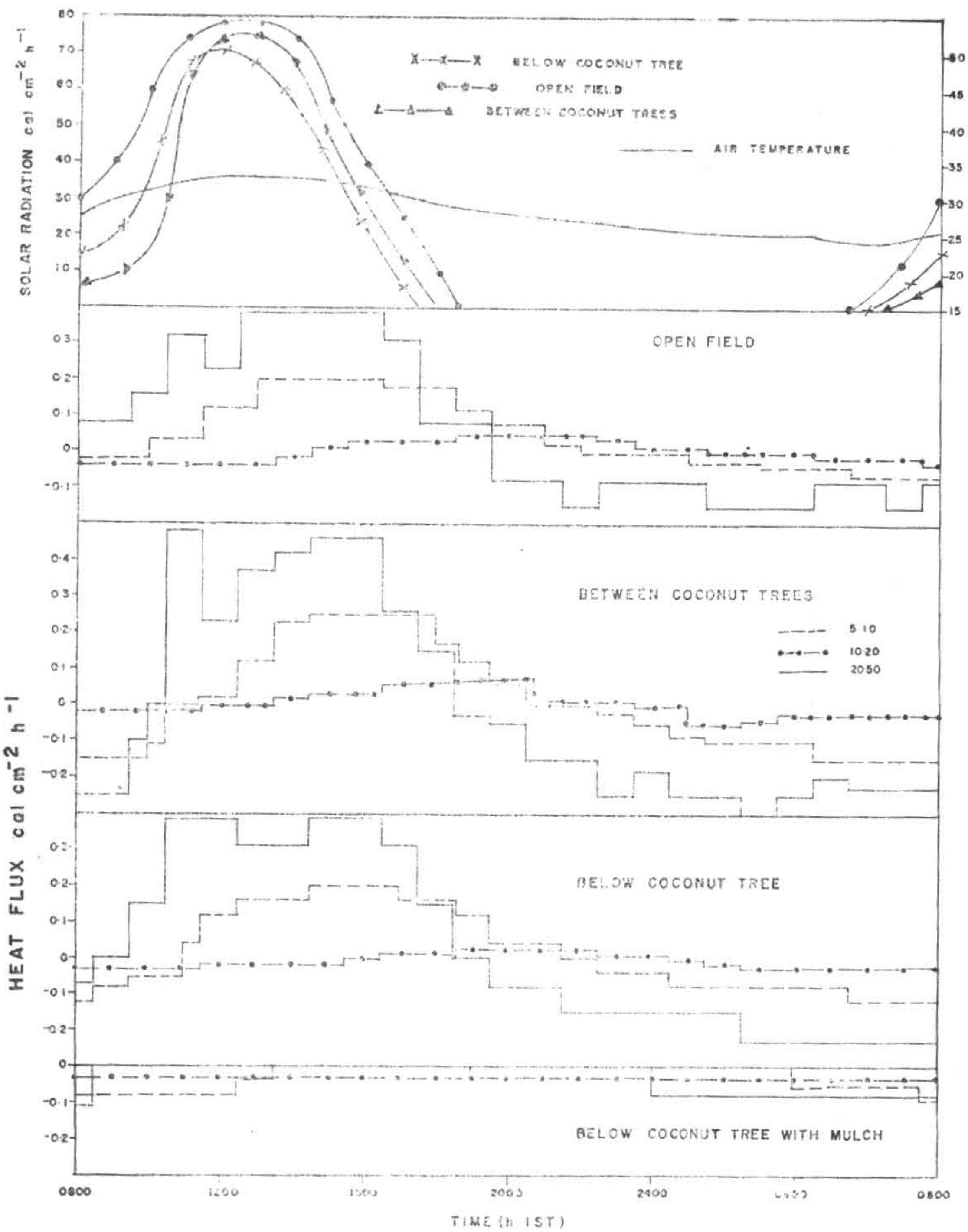

Fig. 1(a). Diurnal variations of heatflux on a summer day (20-21 April 1983) in a coconut garden at Kottamparamba

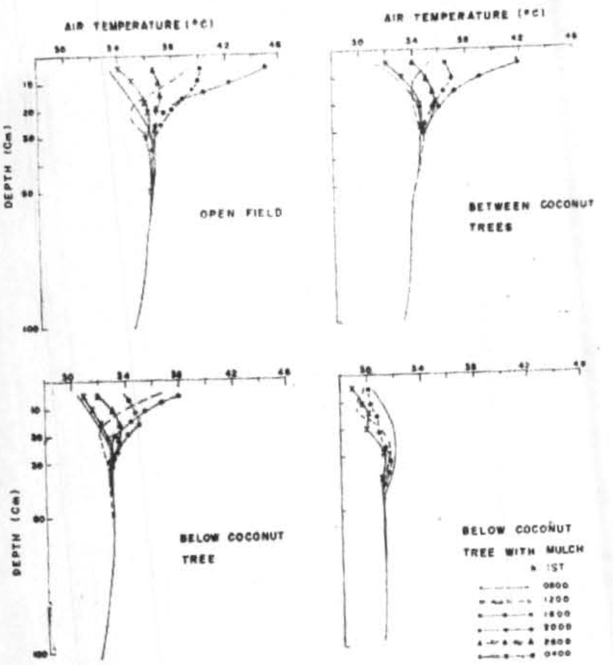

Fig. 1 (b). Diurnal variations of profile soil temperature in a coconut garden at Kottamparamba (20-21 April 1983)

Soil temperatures at 5, 10, 15, 20, 30, 50 and 100 cm depths were measured using mercury in glass soil and earth thermometers. The observations were taken from an open field, in between coconut trees, below the coconut tree both with and without mulch. Tree leaves were used as mulch materials spread at 6 cm height and 2 square metres around the basin of the coconut tree. Soil temperature observations were also taken for 2.5 cm depth from the open field. The solar radiation and air temperature were simultaneously recorded.

(b) *Calculation of results*

The following computations were done based on the observations during March 1983 to February 1984 :

The heatflux into a given layer of soil $(Z_2—Z_1)$ was indirectly computed (Johnson and Davies 1927) using :

$$q_{z_2-z_1} = -K \rho C \frac{(T_{z_2} - T_{z_1})}{(Z_2 - Z_1)} \qquad (1)$$

where, q = heatflux in cal cm^{-2} sec^{-1}

K = thermal diffusivity of the soil cm^{-2}sec^{-1}

ρ = density of the soil gm cm^{-3}

C = specific heat of the soil cal deg^{-1}

Thermal conductivity was estimated indirectly from the bulk density, specific heat and diffusivity of the soils. The diffusivity of the soil was calculated based on the lag for attaining the maximum temperatures in a soil layer (Johnson and Davies 1927). The lag between the times of attainment of maximum temperature at depths Z_1 and Z_2 is given by :

$$L = (Z_2 - Z_1) \frac{T}{2\pi} \sqrt{\frac{\pi}{TK}} \qquad (2)$$

from which it follows :

$$K = \left(\frac{Z_2 - Z_1}{L}\right)^2 \frac{T}{4\pi} \qquad (3)$$

The diffusivity value K was obtained from the slope of the graph between $(Z_2 - Z_1)^2$ and L^2.

The heat capacity of the soil per unit volume was calculated from the following equation (deVeries 1963) :

$$C_s = X_s C_s + X_w C_w + X_a C_a \text{ cal cm}^{-2}\,{}^{\circ}\text{C}^{-1} \qquad (4)$$

where C_s is the heat capacity of the soil, X_s, X_w and X_a are the volume fraction of the solid material, water and air respectively and C_s, C_w, C_a their specific heat capacities.

Statistical analysis was also done to find the relationship between heatflux and soil moisture content.

(c) *Experimental conditions*

Weather — The study area experiences a humid tropical climate with a well defined dry period during December to May. The rainfall during 1983 was 3067 mm. The daily mean solar radiation was between 600 & 100 Wm^{-2} with daily values upto 1050 Wm^{-2} and the duration of sunshine was 3-10 hr per day with higher values confined to the summer period of April-May. The air temperature ranged from 23° C to 35° C and relative humidity from 60 to 100 per cent.

Soils — The physical properties of the soil of the experimental location have been reported by Varadan and Reghunath (1983). The soils are latosols (Oxisols Kaolinitic isohyperthermic family of Tropeptic, Eutrorthox in USDA system of classification). The bulk density for the 0-75 cm soil layer is from 1.19 to 1.37 gm cm^{-3}. The gravel (> 2 mm) content in the soil is about 60-72%. The moisture retention ranges from 20.0-24.0% at 0.3 bar to 10.2-12.2% at 15 bar tensions. The soil is highly porous and its porosity is upto 35%. They are rich with aluminium (Al) and iron (Fe) oxides and organic matter content is <1.0%. The observational area has good drainage and it slopes upto 10-15%. The depth to water table fluctuates from 5.0 to 6.5 m for all the period of the year except during June and July where it ranges between 1.5 & 3.5 m.

The heat capacity of the soil according to the Eqn. (4) was 0.4315 cal cm^{-2} °C^{-1} at permanent wilting point (PWP). The thermal diffusivity according to the Eqn. (3) was 0.596×10^{-3} cm^{-2} sec^{-1} at PWP.

Crop — The coconut crop c.v. west coast tall under observation was about 25 years old and square planted with 7×7 m spacing. There were about 20 standing leaves spread in a spiral form in the canopy of the crop which disposes about 20% of the insolation before reaching the soil surface. The insolation was measured with a Licor integrating solarimeter.

3. Results and discussion

The results are discussed in the following order : (a) diurnal variation of soil temperature and soil heatflux

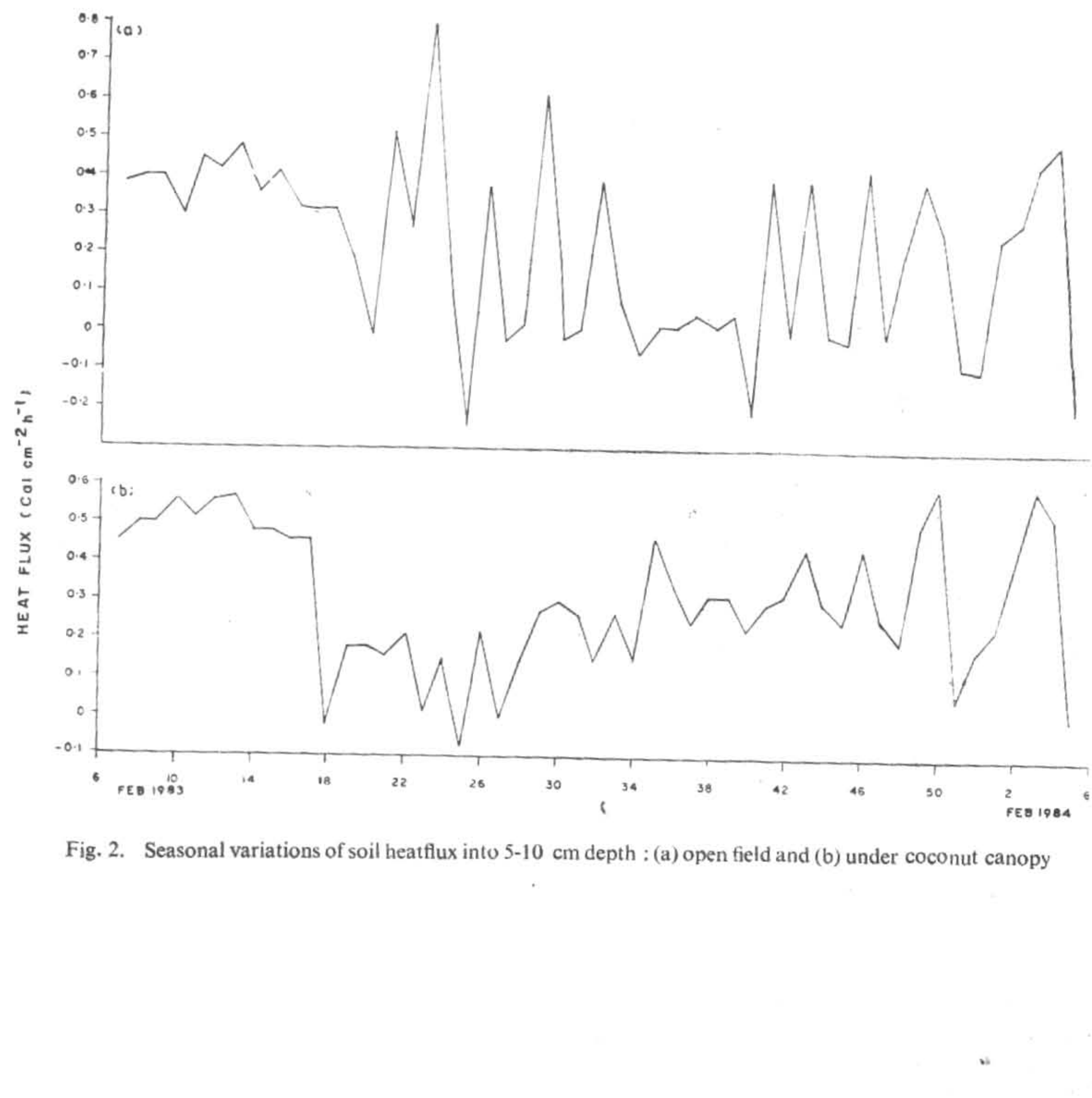

Fig. 2. Seasonal variations of soil heatflux into 5-10 cm depth : (a) open field and (b) under coconut canopy

(b) seasonal variation of soil temperature and soil heatflux and (c) relationship between heatflux and soil moisture content.

(a) *Diurnal variation of soil temperature and soil heatflux* — The diurnal variation of profile soil temperatures upto 100 cm depth and heatflux into the soil layers 5-10 cm, 10-20 cm and 20-50 cm recorded at Kottamparamba campus in an open field, in between coconut trees and below the coconut tree both with and without mulch are shown in Figs. 1(b) & 1(a).

Soil temperature — The range of soil temperatures at 5 cm depth under open field conditions on a peak summer day (20-21 April 1983) was between 33° and 45° C. The temperatures at the same depth were reduced by 2-3° C in the interspace of coconut trees and by 3-7° C below the trees. The reduction of soil temperatures below the trees may be due to the reduced insolation through the canopy. Reduction due to mulch was of the order of 1-7° C at 5 cm depth.

Soil temperatures as high as 62°C were observed at 2.5 cm depth under open field conditions (for 1330 IST). This soil temperature at 2.5 cm in the open field has thus established a gradient upto 29° C with air temperature for the corresponding observation. The highly porous nature of these soils (upto 35%) allows faster depletion of moisture in the surface layers which may be responsible for lower thermal diffusivity in this layer. Such high temperature gradients are not observed at lower depths as the moisture content also increased with depth. The high soil temperatures upto 62°C may also be due to the presence of greater proportion of oxides of Fe and Al in these soils which have low specific heat. The daily surface temperature wave was discernible to a maximum depth of 40 cm.

Soil heatflux — The heatflux into 5-10 cm soil layer was between +0.412 and —0.165 cal $cm^{-2}hr^{-1}$ in the open field whereas it was between +0.494 and —0.296 cal $cm^{-2}hr^{-1}$ both below the trees and in the interspace of trees. Thus the diurnal range of soil heatflux was higher in coconut garden than in the open field. The higher range of heatflux in coconut garden may be due to the sub-surface matting of roots which will reduce the thermal diffusivity and thus creating a higher temperature gradients with the change of day and night time conditions. The direction of heatflow was negative till 0900 IST under coconut garden unlike in the open field due to the interception of insolation by the canopy which will be maximum when solar inclination is also maximum during both early and late hours of the day. The lag for reversing of heatflow direction varies with depth and it is negligible at 50-100 cm layer. The heatflux between 2.5 & 5.0 cm layer under open field was between +6.42 and —1.98 cal $cm^{-2}hr^{-1}$. Such reversing of temperature gradients within a day also influences the day to day soil moisture distribution within the layers of the soil profile (Rosenberg 1974).

Mulching with natural materials like tree leaves around coconut trees is a common practice in this humid tropical region for conservation of soil moisture and optimization of soil temperature. Under mulched conditions which was done around the basin of the tree only, the heatflux into 5-10 cm soil layer was always either at negative or at equilibrium and ranges between 0 and —0.082 cal $cm^{-2}hr^{-1}$. Mulch stabilizes the surface soil temperatures whereas there will be a continuous subsurface lateral flow of heat from the surrounding unmulched area into the mulched area which may be responsible for the small negative heatflow or flow at equilibrium.

(b) *Seasonal variations in soil temperature and soil heatflux* — The soil temperature (1430 IST) ranges from 26° C to 45° C at 5 cm and from 26° to 42° C at 10 cm throughout the year.

The comparative seasonal variation of heatflux into 5.10 cm soil layer based on weekly means of 1430 IST soil temperature observations between open field and the interspace of coconut trees is shown in Fig. 2.

The maximum heatflux into 5-10 soil layer was +0.849 cal $cm^{-2}hr^{-1}$ in the open field and +0.609 cal $cm^{-2}hr^{-1}$ under canopy. For a given season on rainy days, there were many negative heatfluxes in open field for 1430 IST observation while similar such observations are not seen under the canopy. This may be due to insufficient drip of rainwater through canopy reaching the surface soil to influence the temperature. During peak rainy season, *viz.,* June-August, the heatflux at 1430 IST on individual days was at equilibrium or at negative for maximum number of days compared to the heatflux values computed on weekly basis. This may be due to saturated moisture conditions of the soil which increases thermal diffusivity and hence equilibrium heatflow during the period.

(c) *Relationship between soil heatflux and soil moisture* — The soil heatflux has given a nonsignificant statistical relationship with the soil moisture contents within the 75 cm depth of the soil. The inefficient capillary movement of water in these porous soils in response to temperature gradients may be the reason for such relationship. The availability of more moisture in the lower layers of these soils (Varadan and Raghunath 1983) corroborates the above observation regarding the soil temperature influence on soil moisture.

4. Summary and conclusions

An analysis of profile soil temperatures of an oxisol observed between coconut trees and the open field has been made to estimate the heatflux in different soil layers. The study area is in a typical midland laterite and has humid tropical conditions.

Surface (2.5 cm) soil temperatures during summer goes upto 62° C and it ranges between 33° and 45° C at 5 cm depth in an open field . The coconut canopy and mulching around the basin of the trees reduced soil temperatures by 2-7° C and 1-7°C respectively at 5° cm depth.

The heatflux into 5-10 cm on a summer day ranges from +0.412 to —0.162 cal $cm^{-2}hr^{-1}$ in an open field whereas it is between +0.494 & —0.296 cal $cm^{-2}hr^{-1}$ in the coconut garden. The surface fluxes into 2.5-5.0 cm layer in the open field were upto +0.849 cal $cm^{-2}hr^{-1}$. Such high temperature gradients and fluxes prevailing in the summer period needs to be optimised for proper growth conditions by suitable management practices and more so at establishment stage of the crops.

Mulching around the basin showed a negative heatflow or flow at equilibrium. The seasonal heatflux has also been analysed.

The soil heatflux has no significant relationship with moisture content in these soils.

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