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Simultaneous Measurement of Crop Canopy Temperature and Moisture using Canopy Thermal Inertia

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ABSTRACT

In order to operationalize and economize remote sensing applications for simultaneous determination of crop canopy moisture and temperature, recourse is taken through thermal inertia measurements in rice crop. The equation for thermal inertia measurement of soil is modified for canopy thermal inertia by measuring actual canopy temperature with the help of infra-red thermometer. Canopy moisture is measured using prevailing physiological methods. The relationship between canopy thermal inertia and its moisture status is shown from actual measurement of canopy moisture to be related to parameters like the relative water content and moisture content of leaves in the rice canopies.

Introduction

Crop canopy moisture and canopy temperature are two important parameters which control the energy fluxes from the surface. These in turn determine the biospheric processes at local scales and the atmospheric behavior at regional scales (Schmugge, 1990). In the studies by Xue and Cracknell (1995) and Sen Lu et. al. (2009) different models and methods were shown to correlate thermal inertia of soil to its soil moisture. Panda (1993) showed that thermal inertia of soil can be determined through one time measurement of the surface temperature following periodic heating theory. In the present study the same principle has been extended to obtain thermal inertia of rice crop canopy. Later, these thermal inertia values were correlated with observed leaf moisture status to work out an equation for predicting crop canopy moisture. The present study shows a relationship between thermal inertia and canopy moisture. This provides, in principle, a method for simultaneous measurement of canopy moisture and temperature.

Materials and Methods

Rice variety Aditya was grown in IARI farm, New Delhi, during crop year 1993-94. Periodic measurements were taken on canopy temperature with the help of Telatemp Infra-red thermometer during the crop growing season. Simultaneously laboratory measurements on canopy water status was evaluated in terms of relative water content (RWC) and percentage leaf moisture content (LMC).

Relative water content: Relative water content was measured using Barrs and Weatherly (1962) method. Leaves were sliced into pieces of approx. 1 cm size and weighed. These pieces were dipped into distilled water for 3 hours to achieve full turgidity and weighed again. The samples were then oven dried at 85^{0}C till a constant mass is achieved. The RWC was calculated using;

RWC= [(Fresh mass - Dry mass)/ (Turgid mass –Dry mass)] × 100 …(1)

Leaf Moisture Content (LMC)

Fresh weight of leaves was taken. Thereafter samples were dried in the oven at 85^{0}C till a constant mass was achieved. LMC on fresh mass basis was calculated using

LMC = [(Fresh mass - Dry mass)/ (Fresh mass)] × 100 …(2)

The time of sampling was kept at 12:30 P.M local time ±0.5 hrs.

Thermal Inertia

Following the periodic heating theory, the thermal inertia (P) of rice canopy was evaluated using the formula (Elachi, 1987, Panda 1993);

$$P = [I_o \, Cos\,(\Phi-\delta\,)/\,T\sqrt{w}\,] \times Cos\,(wt-\Theta + \pi/4) \quad \ldots(3)$$

where

I_o is the intensity of solar radiation received at the top of the earth's atmosphere on the day of observation.

Φ is the latitude of the place (28.38^o for Delhi)

δ is the solar declination on the day of observation (taken from ephemeris)

T is the temperature of canopy

w is the diurnal angular frequency of periodic heating and

Θ is the temperature lag angle

t = time

Table 1. Measured and calculated canopy parameters (Time of observation: 12:30 PM local time ±0.5 hrs)

Date of observation	Canopy temperature (^{o}C)	RWC (%)	LMC (%)	P (Cal/m^2/^{o}K/s$^{1/2}$)	P^2
19.7.93	35.9	94.1	69.3	118.38	14014
	35.1	94.7	69.1	118.89	14087
	34.8	94.6	68.5	118.80	14114
29.7.93	32.4	86.5	67.7	123.11	15156
	32.2	86.3	68.2	123.19	15176
	32.1	86.8	68.0	123.19	15176
10.8.93	33.4	77.4	67.0	118.04	13933
	34.3	76.2	67.8	117.69	13851
	35.0	74.6	68.6	117.42	13788
16.8.93	33.2	72.3	68.7	117.50	13806
	35.9	71.7	68.2	116.44	13558
	34.5	75.0	67.6	116.96	13681
20.8.93	32.2	80.9	66.2	117.32	13763
	33.1	77.3	66.8	116.97	13682
	32.0	78.1	65.2	117.39	13781
24.8.93	32.5	82.4	67.4	117.58	13592
	31.3	84.4	67.8	117.04	13699
	31.0	83.2	65.5	117.16	13726
28.8.93	30.5	81.1	64.8	117.66	13610
	30.0	84.7	65.5	116.85	13655
	29.4	82.3	66.1	117.09	13709
13.9.93	26.7	73.5	65.7	114.38	13083
	26.8	73.7	65.7	114.35	13075
	26.1	76.3	66.1	114.61	13136
16.9.93	29.5	84.1	65.4	112.44	12643
	28.8	81.5	63.9	112.70	12702
	27.8	85.1	64.8	113.08	12787
20.9.93	32.4	83.2	65.4	110.10	12122
	32.8	83.9	66.3	109.99	12176
	31.8	81.7	64.8	110.34	12176
27.9.93	33.2	81.2	62.6	107.48	11554
	31.7	81.6	62.2	108.02	11668
	31.5	81.1	61.2	108.09	11683
5.10.93	36.2	80.2	61.4	103.48	10709
	36.8	79.8	61.5	103.29	10688
	36.0	79.2	61.5	103.55	10723

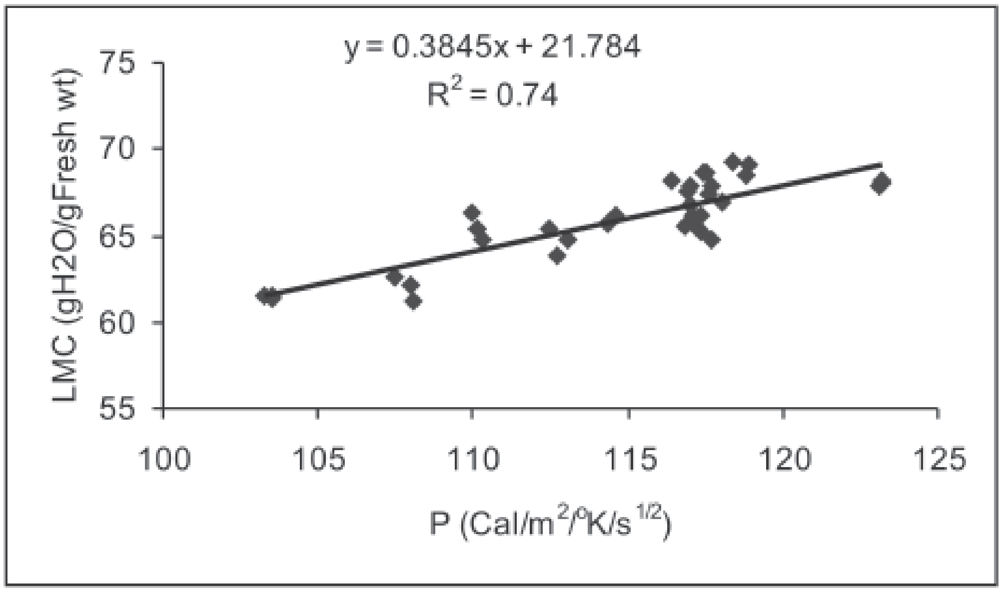

Fig. 1. Leaf moisture content calibration curve against thermal inertia, P

The P and P^2 values were then correlated with RWC and LMC to establish statistically predictive equations.

Results and Discussions

The calculated values of thermal inertia along with experimentally observed RWC and LMC values are given in Table-1. Rose 1966 showed that both volumetric heat capacity and thermal conductivity of soil increases with soil moisture content. Assuming a similar situation hold good for crop canopy, as well, one may expect that square of canopy thermal inertia should vary linearly with leaf moisture content (since P^2 is proportional to the product of volumetric heat capacity and thermal conductivity). Thus P^2 values were also calculated and are also presented in Table 1.

The values of correlation coefficient of P versus RWC worked out to be very poor being 0.255 whereas the correlation coefficient (R^2) of P versus LMC was 0.74 significant at 5% confidence level. Similarly it was found that the values of correlation coefficient of P^2 versus RWC worked out to be very poor being 0.261 whereas the correlation coefficient of P^2 versus LMC was 0.76, significant at 5% confidence level.

The prediction values of leaf moisture content from canopy thermal inertia measurements can be estimated from the following regression equations;

$$LMC = 0.3845\ P + 21.784\ (R^2=0.74;\ p=0.05)$$

$$LMC = 2.6265 *(P^2)^{0.3398}\ (R^2=0.76;\ p=0.05)$$

The calibration curves from these leaf moisture content values are presented in Fig. 1 and Fig. 2.

Conclusion

From the above experiments it has been shown, how the canopy thermal inertia can be evaluated from the single time canopy temperature measurements and once this was done how the canopy moisture can be predicted using an appropriate regression equation since there exists a curvilinear correlation between P^2 and leaf moisture content. Although the present study has been confined to the ground level measurements. It can be easily translated to satellite borne remote sensing instruments equipped with the thermal band spectrometer for routine measurement of the canopy temperature. The canopy moisture status can therefore be evaluated through canopy thermal inertia. The present thermal infra-red technique exhibits great ease and holds high promise as an alternative to the microwave remote sensing for monitoring canopy moisture.

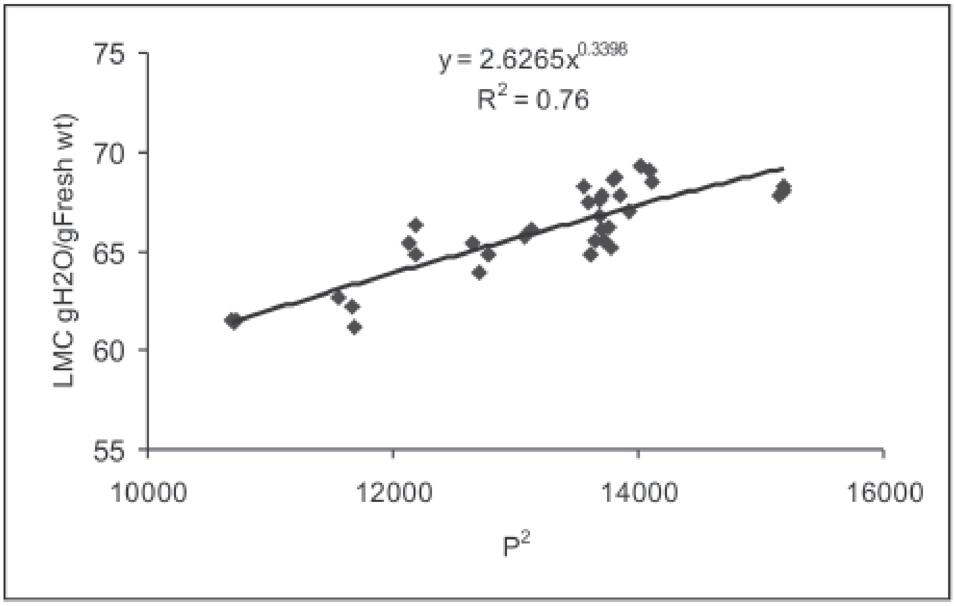

Fig. 2. Leaf moisture content calibration curve against P^2

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