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HCMM ENERGY BUDGET DATA AS A MODEL INPUT FOR ASSESSING REGIONS OF HIGH POTENTIAL GROUNDWATER POLLUTION

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ABSTRACT

A field study was conducted in a barley [Hordeum vulgare L.] canopy to assess the potential for extracting canopy temperature information from radiometric measurements at incomplete cover. Composite temperatures consisting of emitted and reflected longwave radiation from the barley and the soil background were measured by a nadir-viewing infrared radiometer. Canopy temperatures were measured by an infrared radiometer at a 30° angle from the horizontal. Soil temperatures were measured with thermocouples.

Composite temperatures were 0.5 to 11.5 C higher than canopy temperatures with the largest difference occurring at low canopy cover. The correlation between composite and canopy temperature for data acquired throughout the growing season was not significant. An equation which considered emitted radiation from both the canopy and the soil background, and which included reflected sky radiance was used to predict crop temperatures from nadir measurements. Predicted temperatures agreed with observed values ($r^2 = 0.88$), and the prediction accuracy was independent of canopy cover. When emissivity corrections were not applied, prediction accuracy varied with percent cover with largest errors occurring at low cover. Prediction accuracy also varied with canopy cover when appropriate emissivities were used but sky radiance was ignored. Results indicate that canopy temperatures can be estimated from nadir measurements at incomplete cover if percent cover, soil temperature, and sky radiance are known.

Additional index words: Emissivity, remote sensing, radiometry, radiance, longwave radiation.

INTRODUCTION

Remotely-sensed surface temperatures can be useful for many agricultural applications including evapotranspiration modeling (Brown and Rosenberg, 1973; Stone and Horton, 1974; Heilman and Kanemasu, 1976; Soer, 1980), soil moisture detection (Idso et al., 1975; Idso and Ehrler, 1976; Schmugge et al., 1978; Heilman and Moore, 1980), plant stress detection (Wiegand and Namken, 1966; Jackson et al., 1977; Ehrler et al., 1978), yield prediction (Idso et al., 1977; Idso et al., 1979) and irrigation scheduling (Jackson et al., 1977). Most studies which have used remote measurements have been restricted to bare soils or fully developed crop canopies because of the complexities involved in interpreting thermal data at less than full cover.

Much of the complexity results because the remote sensing instrument measures emitted and reflected radiation from vegetation and soil differing in temperature and emissivity. Hatfield (1979) reported that differences between angular and vertical infrared thermometer measurements of canopy temperatures were greatest at 20 to 50% cover and decreased as canopy density increased. He speculated that differences were enhanced by emissivity variations. Millard et al. (1980) found that for canopies covering at least 85% of the soil surface, airborne measurements of plant temperatures differed from ground measurements by less than 2 C. At 50% cover, differences were as large as 9 C. Investigators have shown that even at full cover thermal radiance from the soil surface can affect remote temperature measurements of crop canopies (Blad and Rosenberg, 1976).

Incomplete plant canopies are important remote sensing targets because of the potential benefits arising from early assessment of crop condition. Jackson et al. (1979) presented a model for extracting crop temperature information from a composite of soil and plant temperatures measured by a sensor scanning perpendicular to crop rows. He found that if a critical scan angle (determined from reflectance measurements) was exceeded, the temperature obtained from the scanner was that of sunlit vegetation. He also found that the extraction process was difficult for canopies having low percent cover.

We evaluated relationships among percent cover, soil and crop temperature, and radiometric measurements of canopy temperature, and assessed the potential for extracting canopy temperature using temperature measurements from a nadir-viewing radiometer. We also assessed the errors associated with neglecting emissivity and sky radiance corrections.

MATERIALS AND METHODS

Experiments were conducted on a 25m x 300m field of Volga loam [fine-loamy over sandy or sandy-skeletal, mixed (calcareous), frigid, Cumulic Haplaquoll] at the South Dakota State University Agricultural Engineering Research Farm located 8 km south of Brookings, South Dakota. Larker barley [*Hordeum vulgare* L.] was planted in the field at 15-cm row spacings (north-south rows) at a population of 2.5 million plants ha.$^{-1}$ The barley was not irrigated. Surface roughness of the soil was minimal.

Surface soil temperatures (approximately 1 mm below the soil surface) were measured with copper-constantan thermocouples at two locations (A and B) within the field. For each location, three thermocouples were wired in parallel to obtain an average measurement of shaded and sunlit soil which approximated surface temperature.

Composite temperatures consisting of contributions from the soil surface and the barley were measured at 1330 Local Standard Time (LST) on clear days with a precision radiation thermometer (Model PRT-5, Barnes Engineering Co.)[3/] at a vertical position (zero degree look angle measured from nadir) at a height of 2 m above the canopy. The temperature resolution of the 20° field of view PRT was ±0.5 C in the 8-14 μm wavelength interval. Canopy temperatures were measured with the PRT-5 at a height of 1 m above the canopy and a look angle of 30° from the horizontal (Millard et al., 1980) pointing to the east and the west (perpendicular to row direction). At that angle, direction, and canopy cover, minimal radiance contributions from the soil were detected by the PRT-5. Canopy temperatures were corrected for emissivity and sky radiance.

Emissivities of the canopy at full cover were measured using a procedure similar to that described by Fuchs and Tanner (1966). We used a painted aluminum plate with an emissivity of 0.52 rather than an anodized plate to determine sky radiance (Blad and Rosenberg, 1976). Soil emissivities were measured on a bare soil plot adjacent to the barley field.

Soil water contents (0 to 4-cm layer) for each location were determined gravimetrically on soil samples collected at the time of the temperature measurements. Percent cover was determined using 35 mm color infrared slides of the canopy (photographed from a vertical position approximately 1 m above the canopy) projected on a random dot grid. Figure 1 shows seasonal trends in percent cover of the barley canopy.

[3/] Mention of a trade name does not imply endorsement by S.D. State Univ.

RESULTS AND DISCUSSION

In the discussion that follows composite temperature refers to apparent temperatures measured by the nadir-viewing PRT-5. Canopy temperature refers to temperature measured by the PRT-5 at a 30° angle from the horizontal.

During the investigation, composite temperatures were 0.5 to 11.5 C higher and surface soil temperatures 1.5 to 20 C higher than canopy temperatures (Fig. 2). As expected, differences between composite and canopy temperature decreased as canopy cover increased and less emitted radiation from the warm soil background was detected by the radiometer. The correlation between composite and canopy temperature was non-significant ($r = 0.41$).

Millard et al. (1980) found that errors from assuming nadir-viewing thermal scanner measurements represented actual canopy temperature were a linear function of canopy cover. We found a highly significant linear relationship ($r^2 = 0.52$) between the composite-canopy temperature difference and percent cover (Fig. 3). However, the considerable scatter in our data suggests that it may not be possible to assess errors in determining canopy temperature using only canopy cover information as Millard et al. (1980) suggested.

We assumed the longwave radiation flux from a canopy and the soil background could be approximated by the relationship

$$R = f_c \varepsilon_c \sigma T_c^4 + (1-f_c)\varepsilon_s \sigma T_s^4 + f_c(1-\varepsilon_c)B^* + (1-f_c)(1-\varepsilon_s)B^* \qquad [1]$$

where R ($W\ m^{-2}$) is longwave flux, f_c is percent cover expressed as a fraction, ε_c is canopy emissivity, ε_s is soil emissivity, T_c (K) is canopy temperature, T_s (K) is surface soil temperature, σ ($5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$) is the Stefan-Boltzmann constant, and B^* ($W\ m^{-2}$) is longwave sky radiance. The first two terms on the right-hand side of equation [1] represent longwave radiation emitted from the canopy and exposed soil background, respectively. The last two terms represent sky radiance reflected from the canopy and exposed soil background, respectively. The complex relationship of emitted and reflected radiation between the canopy and the soil is ignored in equation [1]. Equation [1] also does not partition fractions of shaded and sunlit leaves, or fractions of exposed soil background which are shaded and sunlit. Canopy temperature can be expressed by rearranging equation [1] to give

$$T_c = \left[\frac{R-(1-f_c)\varepsilon_s T_s^4 - f_c(1-\varepsilon_c)B^* - (1-f_c)(1-\varepsilon_s)B^*}{f_c \varepsilon_c \sigma}\right]^{1/4} \quad [2]$$

We compared observed values of T_c with values predicted using equation [2] and measured values of f_c, T_s and B* (Fig. 4). R was calculated from measurements of composite temperature using the relationship $R = \sigma T_{comp}^4$ where T_{comp} is composite temperature. A measured value of 0.98 was used for ε_c. Soil emissivity varied with water content as shown in Fig. 5. Linear regression analysis of predicted versus observed canopy temperature yielded a slope of 1.04, an intercept of -0.53, and a r^2 of 0.88. Differences of observed from predicted values ranged from -1.84 to +2.50 C. The prediction accuracy of equation [2] was independent of canopy cover. The correlation between predicted minus observed canopy temperature and percent cover was 0.26 (non-significant).

Many investigators have discussed the importance of correcting radiometric data for emissivity variations. Bartholic et al. (1972) reported temperature errors ranging from 1.9 C for bare, dry soil to 0.8

for cotton which arose from assuming an emissivity of 1. Jackson et al. (1977) reported a nearly constant error of 1.7 C for wheat temperature by not correcting for emissivity. Similarly, Sutherland and Bartholic (1977) found that assuming an emissivity of 1 produced errors on the order of 1.0 C for complete canopies.

Figure 6 compares observed canopy temperatures with values predicted using emissivities of 1 for the soil and canopy in equation [2]. Linear regression analysis of predicted versus observed canopy temperatures yielded a slope of 1.14, an intercept of -5.08, and a r^2 of 0.76. Differences of observed from predicted values ranged from -6.43 to +1.70 C.

Prediction accuracy when values of 1 were used for ε_c and ε_s was a function of canopy cover as shown in Fig. 7. Greatest errors occurred at low percent cover when radiance contributions from the soil were greatest. The magnitude of the emissivity correction depends not only on canopy cover, but also on soil type and water content. Emissivities ranging from 0.90 to 0.93 for dry sand to 0.98 to 0.99 for loamy soils have been reported (Sellers, 1972; Sutherland and Bartholic, 1977; Tyalor, 1979).

Figure 8 compares observed canopy temperatures with values predicted using measured emissivities in equation [2], but neglecting the reflected sky radiance components. Differences of observed from predicted values ranged from 0.8 to 10.7 C. Regression analysis of predicted versus observed canopy temperatures gave a slope of 0.66, an intercept of 7.74 and a r^2 of 0.66.

Prediction accuracy, when neglecting the B* terms, changed with canopy cover, with greatest errors occurring at low cover (Fig. 7). The sum of the reflected B* components ranged from 13.2 W m^{-2} at 23% cover to 5.6 W m^{-2} at 90% cover.

This study has shown that accurate estimates of canopy temperatures at incomplete cover are possible from nadir-viewing radiometers if appropriate considerations are given to soil background radiance, emissivity and sky radiance. Remote sensing evaluations of canopy cover have been demonstrated (Heilman et al., 1977; Kanemasu et al., 1977; Tucker et al., 1978; Jackson et al., 1979), and sky radiance can be estimated from prevailing sky conditions (Soer, 1980). Estimating the radiance contribution from the soil background remains a difficult problem. Models have been developed for estimating surface and near surface soil temperature (Behroozi-Lar et al., 1975; Pratt and Elyett, 1979; Meyer et al., 1975) and they can potentially be extended to crop canopies. All three factors must be included in models to accurately assess canopy temperature at low canopy cover.

LITERATURE CITED

Bartholic, J.F., L.N. Namken, and C.L. Wiegand. 1972. Aerial thermal scanner to determine temperatures of soils and of crop canopies differing in water stress. Agron. J. 64:603-608.

Behroozi-Lar, M., B.K. Huang, and H.D. Bowen. 1975. Simulation of soil temperature profile using PCAP. Paper No. 75-1037, 1975 Annual Meeting American Society of Agricultural Engineers.

Blad, B.L., and N.J. Rosenberg. 1976. Measurement of crop temperatures by leaf thermocouple, infrared thermometry and remotely sensed thermal imagery. Agron. J. 68:635-641.

Brown, K.W., and N.J. Rosenberg. 1973. A resistance model to predict evapotranspiration and its application to a sugar beet field. Agron. J. 65:341-347.

Ehrler, W.L., S.B. Idso, R.D. Jackson, and R.J. Reginato. 1978. Wheat canopy temperature: relation to plant water potential. Agron. J. 70:251-256.

Fuchs, M., and C.B. Tanner. 1966. Infrared thermometry of vegetation. Agron. J. 58:596-601.

Hatfield, J.L. 1979. Canopy temperatures: the usefulness and reliability of remote measurements. Agron. J. 71:889-892.

Heilman, J.L. and E.T. Kanemasu. 1976. An evaluation of a resistance form of the energy balance to estimate evapotranspiration. Agron. J. 68:607-611.

Heilman, J.L., E.T. Kanemasu, J.O. Bagley, and V.P. Rasmussen. 1977. Evaluating soil moisture and yield of winter wheat in the Great Plains using Landsat data. Remote Sensing Environ. 6:315-326.

Heilman, J.L., and D.G. Moore. 1980. Thermography for estimating near-surface soil moisture under developing crop canopies. J. Appl. Meteor. 19:324-328.

Idso, S.B., T.J. Schmugge, R.D. Jackson, and R.J. Reginato. 1975. The utility of surface temperature measurements for the remote sensing of surface soil water status. J. Geophys. Res. 80:3044-3049.

__________, and W.L. Ehrler. 1976. Estimating soil moisture in the root zone of crops: a technique adaptable to remote sensing. Geophys. Res. Lett. 3:23-25.

__________, and R.D. Jackson, and R.J. Reginato. 1977. Remote sensing of crop yields. Science 191:19-25.

__________, J.L. Hatfield, R.D. Jackson, and R.J. Reginato. 1979. Grain yield prediction: extending the stress-degree-day approach to accommodate climatic variability. Remote Sensing Environ. 8:267-272.

Jackson, R.D., R.J. Reginato, and S.B. Idso. 1977. Wheat canopy temperature: a practical tool for evaluating water requirements. Water Resour. Res. 13:651-656.

Jackson, R.D., R.J. Reginato, P.J. Pinter, Jr., and S.B. Idso. 1979. Plant canopy information extraction from composite scene reflectance of row crops. Appl. Optics 18:3775-3782.

Kanemasu, E.T., J.L. Heilman, J.O. Bagley, and W.L. Power. 1977. Using Landsat data to estimate evapotranpsiration of winter wheat. Environ. Manage. 1:515-520.

Meyer, C.R., J.A. Tunheim, and D.G. Moore. 1975. Heat-flow temperature model for remotely mapping near-surface water tables by thermography. S.D. Academy of Science 54:23-32.

Millard, J.P., R.J. Reginato, R.C. Goettelman, S.B. Idso, R.D. Jackson, and M.J. LeRoy. 1980. Experimental relations between airborne and ground measured wheat canopy temperatures. Photogram. Eng. and Remote Sensing 46:221-224.

Pratt, D.A., and C.D. Ellyett. 1979. The thermal inertia approach to mapping soil moisture and geology. Remote Sensing Environ. 8:151-168.

Schmugge, T., B. Blanchard, A. Anderson, and J. Wang. 1978. Soil moisture sensing with aircraft observations of the diurnal range of surface temperature. Water Resour. Bull. 14:169-178.

Sellers, W.D. 1972. Physical Climatology. University of Chicago Press, Chicago.

Soer, G.J.R. 1980. Estimation of regional evapotranspiration and soil moisture conditions using remotely sensed crop surface temperatures. Remote Sensing Environ. 9:27-45.

Stone, L.R., and M.L. Horton. 1974. Estimating evapotranspiration using canopy temperatures: field evaluation. Agron. J. 66:450-454.

Sutherland, R.A., and J.F. Bartholic. 1977. Significance of vegetation in interpreting thermal radiation from a terrestrial surface. J. Appl. Meteorol. 16:759-763.

Taylor, S.E. 1979. Measured emissivity of soils in the southeast United States. Remote Sensing Environ. 8:359-364.

Tucker, C.J. 1979. Red and photographic infrared linear combination for monitoring vegetation. Remote Sensing Environ. 8:127-150.

Wiegand, C.L., and L.N. Namken. 1966. Influence of plant moisture stress, solar radiation, and air temperature on cotton leaf temperature. Agron. J. 58:582-586.

LIST OF FIGURES

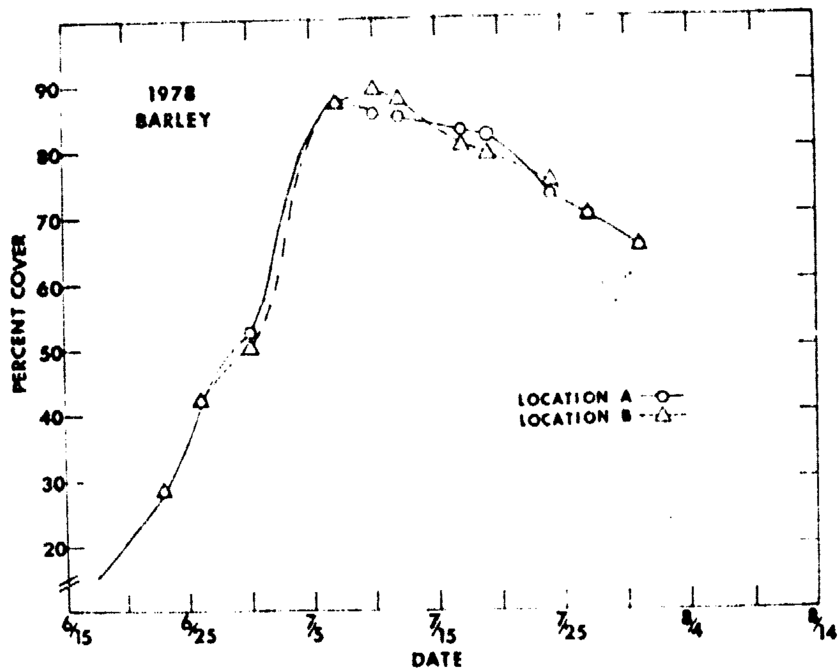

Fig. 1. Seasonal variations in percent cover of the barley canopy. Jointing and heading occurred on 16 June and 19 July, respectively.

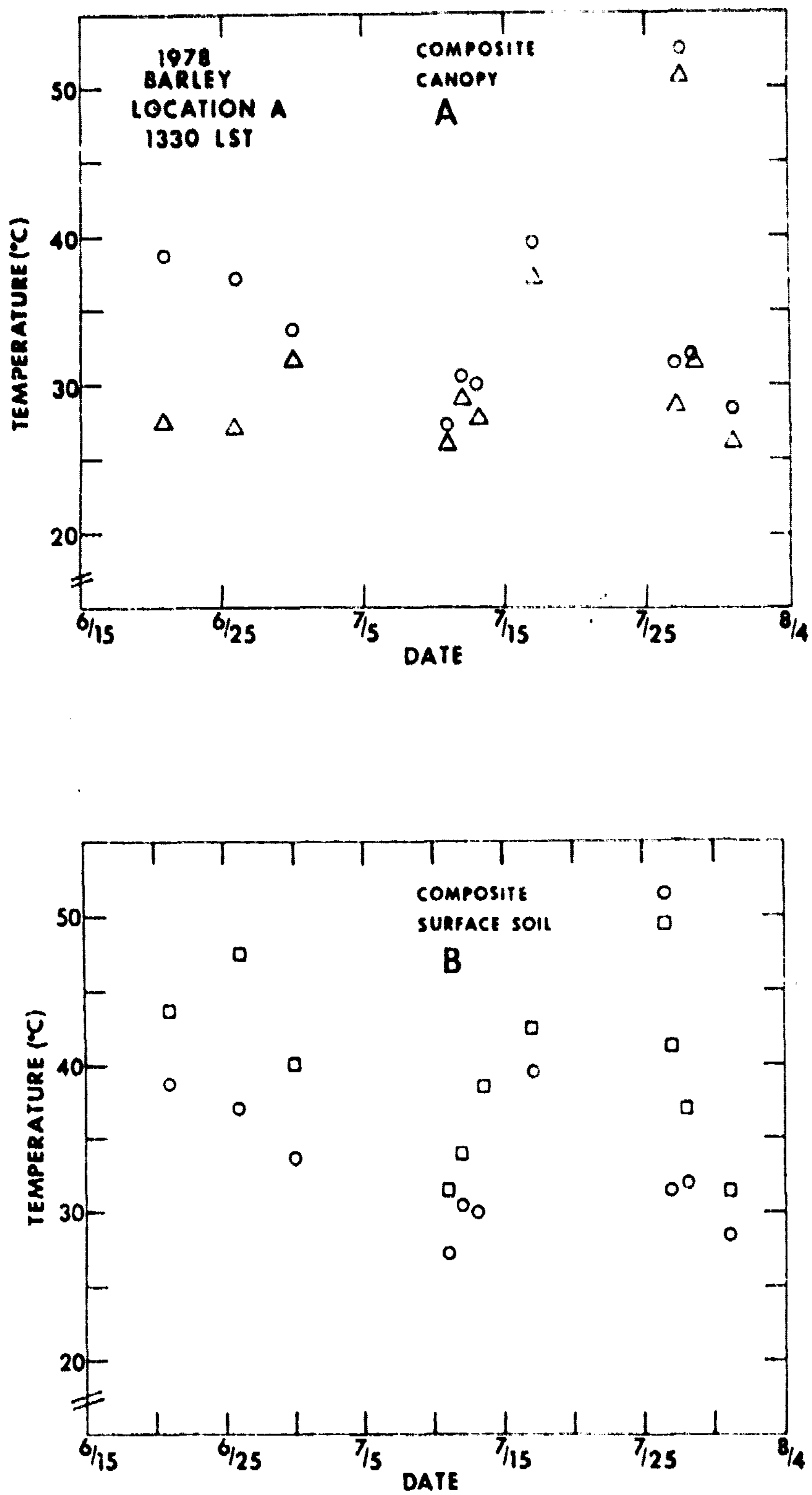

Fig. 2 Comparison of composite temperatures with canopy temperature (A), and surface soil temperature (B) at 1330 LST.

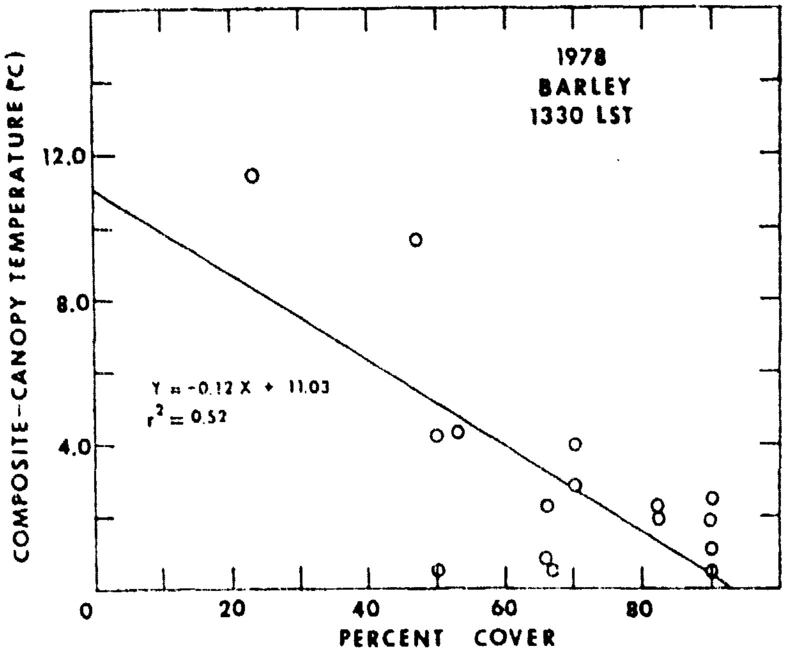

Fig. 3. Composite-canopy temperature difference as a function of percent cover.

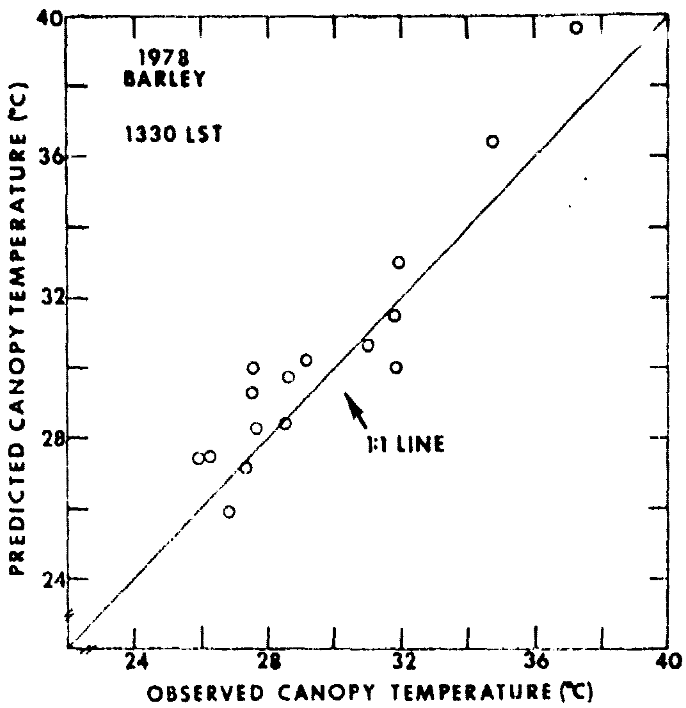

Fig. 4. Comparison of predicted and observed canopy temperatures. Canopy temperatures were predicted using equation [2].

A. Problems

None

B. Accomplishments

Analyses of all data are continuing.

C. Significant Results

Additional dates of HCMM data have been included in the analyses documented in the March 1980 progress report (SDSU-RSI-80-03). Addition of the new data confirmed that HCMM radiometric temperatures corrected for vegetation difference were significantly correlated to both near-surface soil moisture and depth to groundwater.

D. Publications

"Remote sensing of canopy temperature at incomplete cover" to be submitted to Agronomy Journal (see Appendix A).

E. Recommendations

None

F. Funds Expended

$90,596.43

APPENDIX A

Remote Sensing of Canopy Temperature at Incomplete Cover

(Submitted to Agronomy Journal)

REMOTE SENSING OF CANOPY TEMPERATURE AT INCOMPLETE COVER[1/]

J.L. Heilman, W.E. Heilman, and D.G. Moore[2/]

[1/] Contribution No. SDSU-RSI-J-80-05 from the Remote Sensing Institute, South Daktoa State University, Brookings, SD 57007. Research supported in part by NASA under contract no. NAS5-24206, and the State of South Dakota.

[2/] Research Soil Physicist, Research Assistant, and Assistant Director, respectively.

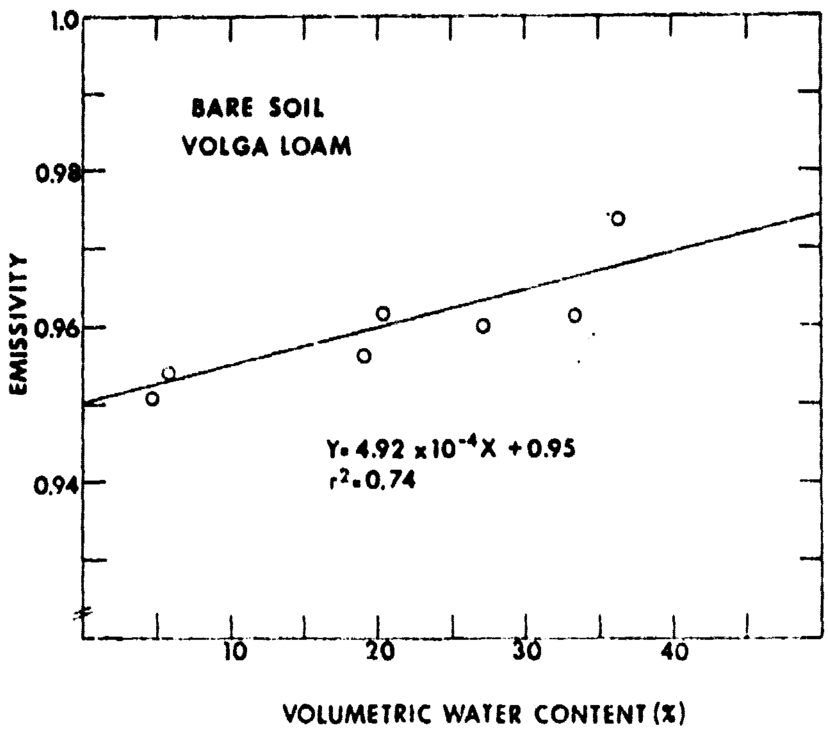

Fig. 5. Relationship between measured soil emissivity and volumetric water content in the 0-4 cm layer.

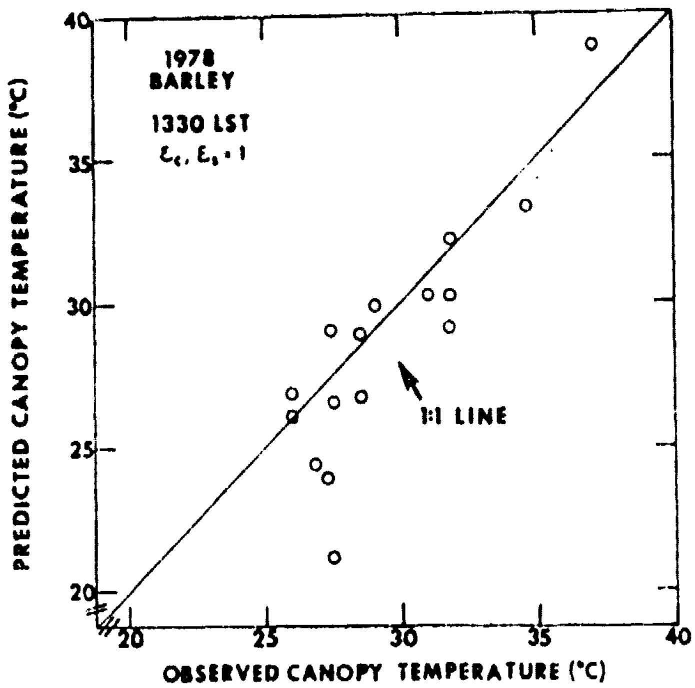

Fig. 6. Comparison of predicted canopy temperatures, using values of 1 for ε_c and ε_s in equation [2], with observed values.

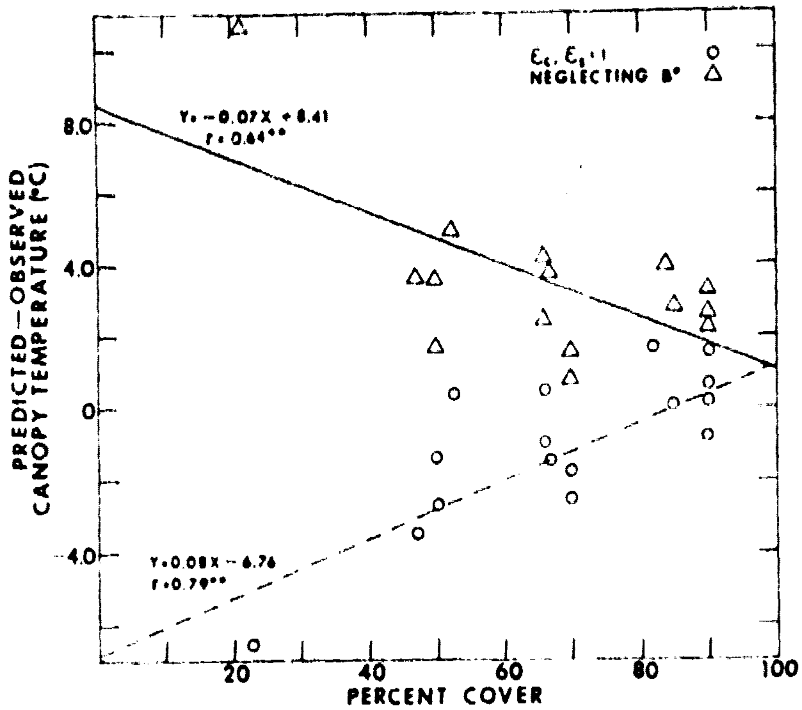

Fig. 7. Predicted minus observed canopy temperatures as a function of percent cover when values of 1 were used for ε_c and ε_s (circles); and when measured values of ε_c and ε_s were used, but sky radiance terms were neglected (triangles).

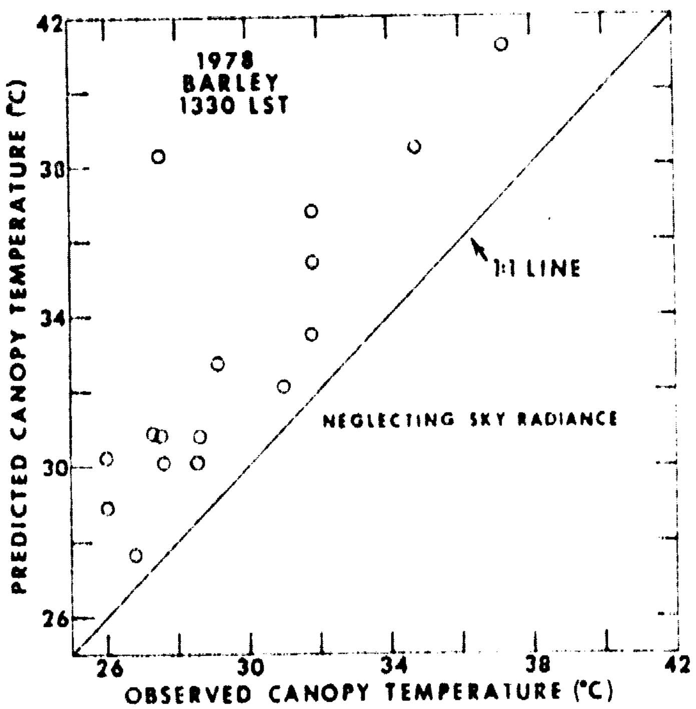

Fig. 8. Comparison of predicted and observed canopy temperatures when measured emissivities were used in equation [2], but reflected sky radiance terms were neglected.