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Attenuation of Soil Microwave Emission by Corn and Soybeans at 1.4 and 5 GHz

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Abstract—**Theory and experiments have shown that passive microwave radiometers can be used to measure soil moisture. However, the presence of a vegetative cover alters the measurement that might be obtained under bare conditions. Significant obstacles to the practical use of this approach are deterministically accounting for the effect of vegetation and developing algorithms for extracting soil moisture from observations of a vegetation-soil complex. The presence of a vegetation canopy reduces the sensitivity of passive microwave instruments to soil moisture variations. Data collected using truck-mounted microwave radiometers were used to examine the specific effects of corn and soybeans canopies.**

Keywords—**Radiometer, soil, moisture, vegetation, canopy, water content.**

I. INTRODUCTION

Although attempts have been made to model the soil-vegetation system, even the most sophisticated approaches must utilize some approximations and parameterizations due to the complex nature of this target. Ultimately, these effects must be incorporated into a deterministic algorithm which utilizes parameters that can be readily measured, hopefully using remote sensing.

A simple model was proposed [1] to account for vegetation effects that utilized the vegetation wet biomass or water contents as the only canopy parameter. Additional studies demonstrated that an improvement could be made by including the single scattering albedo in the modeling approach [2], [3].

Further improvements in vegetation effect models are possible if the canopy structure can be incorporated into the model. One approach to solving this problem is to develop a physically based electromagnetic model of the system. This requires a detailed knowledge of the dielectric properties of the plant constituents [4] and a model to represent the complex and highly variable agrometrical distribution. This approach can work and is valuable in furthering our understanding [5].

An alternative approach to accounting for structure is to develop a parametric representation of the vegetation which could be readily implemented using exciting remotely sensed data. It is hypothesized here that canopy structure is basically a function of the structural crop type, and that for each crop a unique relationship between vegetation water content and attenuation can be established. Multispectral remote sensing could be used to perform crop classification and vegetation water content estimation. This hypothesis was examined using data collected by truck-mounted *C*- and *L* band radiometers over controlled-condition corn and soybean fields.

II. MICROWAVE EMISSION FROM VEGETATION-COVERED FIELDS

Any attempt to model the effects of vegetation on microwave emission must make a number of assumptions and simplifications, since a vegetation canopy is an extremely physical system and is highly variable in all dimensions and parameters. On the scale of an agricultural field a canopy does have some degree of uniformity, and it is the vegetation effects at this scale that are of interest here.

Following the development by Ulaby *et al.* [6] for a uniform layer of vegetation at a given incidence angle and polarization,

$$TB_c = (1 + R_B\alpha)(1 - \gamma)(1 - \alpha)T_v + (1 - R_B)\gamma T_B \qquad (1)$$

where

TB_c	brightness temperature of the canopy observed by a radiometer (K),
T_v	physical temperature of the vegetation canopy (K),
T_B	physical temperature of the background media (K),
γ	transmissivity of the vegetation layer,
R_B	air-background reflectivity,
α	single-scattering albedo.

The transmissivity γ is expressed as a function of the optical depth τ and incidence angle θ as follows:

$$\gamma = \exp(-\tau \sec\theta). \qquad (2)$$

The model described by (1) has been successfully applied for a variety of crops and frequencies [2], [3], [6], [7].

Equation (1) can be simplified if α is assumed to be zero and that $T_v \approx T_B$ [1]. Under these assumptions,

$$e_c = \frac{TB_c}{T_v} = 1 - R_B \exp(-2\tau) \qquad (3)$$

where e_c is the emissivity of the canopy.

Single-scattering albedo should be a function of plant agrometry, polarizaiton, and frequency and, therefore, should vary with the crop type, planting pattern, and stage of growth [2]. There is no established physical relationship between α and any of these parameters. Based on (1) and (2), when the attenutation by the canopy is small ($TB_c \approx TB_B$) and the background is cold ($TB_B = 200$), the value used for α is not important. Sensitivity increases as the canopy temperature increases and diverges from the background temperature.

There are three approaches that can be used to deal with the single-scattering albedo: 1) Assume $\alpha = 0$; 2) use literature values; and 3) estimate through experimental conditions.

The first approach was used with some success in [1]. This approach presumes that the variability in α is small and that the effects of α can be incorporated in τ.

With respect to the second approach, there is limited amount of data on α in the literature. Representative values for selected conditions considered in the current study are: Corn—1.4 GHz $\alpha =$

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0.03 and 5 GHz $\alpha = 0.04$; and soybeans—1.4 GHz $\alpha = 0.05$ and 5 GHz $\alpha = 0.07$. The third approach requires the collection of specific sets of data [2] in each case and would be impractical in any large-scale application.

Regardless of the assumptions made concerning α, the value of τ must also be determined. The approach used here was to measure τ and plant parameter combinations and then try to determine if any relationships between them exist. This approach has been used previously by [1], [3], [7]–[9]. Both theory [8] and experiments [1], [3] have shown that τ is a linear function of the vegetation water content.

III. Experiment Description

All experiments were conducted at the Beltsville Agricultural Research Center. The soil is a loamy sand with a nominal sand fraction of 74% and a clay fraction of 6%. The specific surface area of the soil is approximately 14 cm^3/g.

In 1984, a large corn plot was prepared for this experiment. The row spacing was 0.76 m and the spacing between plants was 0.23 m, resulting in a density of 5.7 plants/m^2. Different sections of this large plot were used on different days.

A series of four measurements were made on a given day: 1) Corn canopy with soil underneath; 2) corn canopy with screens underneath; 3) stubble (canopy removed); and 4) screens in stubble.

Screens were used to provide a background to the vegetation which has a very low emissivity (~ 0.3) as compared to a soil. This approach is similar to that described in [2].

In 1985, two large soybean fields were planted. One had a row spacing of 0.45 m and a plant spacing of 0.09 m, and the other, 0.19 and 0.063 m, resulting in densities of 24 and 81.2 plants/m^2, respectively. It was found that the screen procedures used for corn would not work for soybeans. The problem was that everytime the screens were placed and removed, the canopy was damaged. As an alternative, a water background was used. Water also has a low emissivity which provides a good contrast to soil.

A section of the field was enclosed with wooden boards and used each time. After a set of radiometer data was collected, the section was rapidly flooded to a depth of 10 cm and another set of radiometer data was obtained. To determine the water background emissivity, an artificial pond was constructed at the site with the same dimensions as the flooded section.

Data were also collected for soil backgrounds with and without the vegetation cover. Naturally, the sections that were repeatedly flooded were more vigorous than the dry farming sections. Unfortunately, data could not be collected for as wide a range of vegetation water content as was initially intended due to excessive lodging (bending) of the soybean plants.

Gravimetric soil data were collected concurrently with the microwave observations. Bulk density samples were obtained periodically during the experiments and used to compute volumetric soil moisture. Soil temperature was measured at depths of 2.5 and 15 cm and at the surface with a thermal infrared radiometer. Vegetation density and wet and dry biomass were sampled periodically. The vegetation water content was computed from the difference between the wet and dry biomass values.

L-band (1.4 GHz, 21 cm) and C-band (5 GHz, 6 cm) passive microwave radiometers mounted on an extendable boom were used in these experiments. These instruments have been used since 1978 and are described in [10]. Data were collected at look angles (from nadir) of 10° and 20° for horizontal (H) and vertical (V) polarization. All observations were obtained with the radiometer oriented parallel to the vegetation row direction.

IV. Results

The experimental data covered a wide range of TB values and show no significant trends due to polarization at either C- or L-bands, as illustrated in Fig. 1 for L-band. Results at an incidemce angle of 20° did show TB_H as being slightly larger than TB_V. Since we will focus on the 10° data, the results obtained for H polarization should also apply to V polarization. The model described by (1) and (2) was evaluated using these data. With α specified (published values described previously), (2) was substituted in (1) to solve for τ for each observation. The values of τ were then plotted against the vegetation water content, and selected results are shown in Figs. 2 and 3.

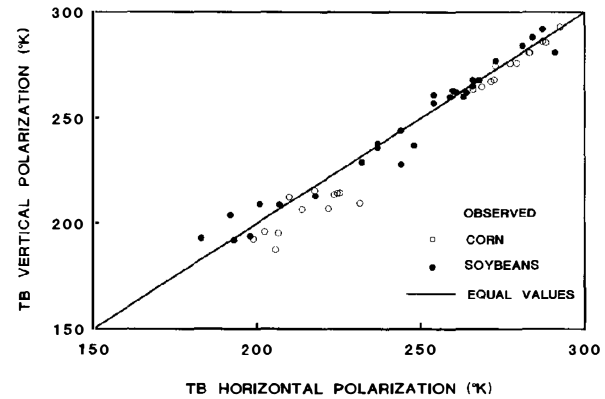


Fig. 1. Observed 1.4 GHz 10° look angle data collected over vegetation canopies with H and V polarizations.

One model of the relationship between τ and W is as follows [1]:

$$\tau = bW \tag{4}$$

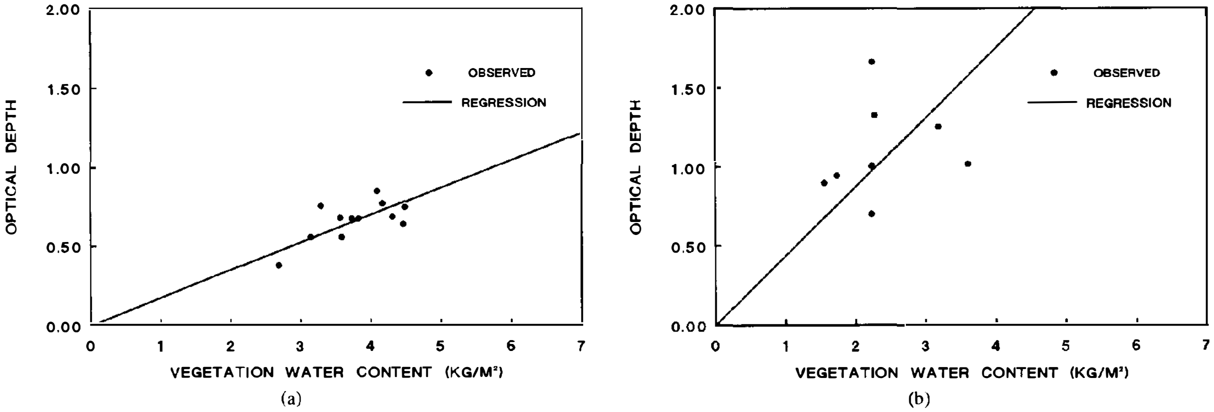
where b is a coefficient, and W is the vegetation water content. Equation (4) was optimized for b using the data in Figs. 2 and 3. The coefficients and standard error of estimate values are listed in Table I. At L-band, the b estimates for both crops are similar, as might be expected from Fig. 3. C-band results are quite different, and for soybeans the difference is very large.

Examining Figs. 2 and 3, it appears that the complete model does explain the observed data. At L-band, for these crops and conditions there is not much difference in the b values of corn and soybeans. C-band observations for corn show a modest increase in b over L-band. Soybean results are quite different and highly variable. This may be the result of wavelength-related interactions with plant components.

The data were also used to fit the model, assuming that $\alpha = 0$. This is the same approach as that used in [1], except that enough data were available to consider the crop type. These results are listed in Table II. In terms of prediction ability, at L-band the model works better when $\alpha = 0$. This could be the result of incorrectly specifying α in the full version. The reverse is true for C-band. This would suggest that scattering is much more important at higher frequencies. The results from the earlier work described in [1] are also listed in Table II. Obviously, the results are similar, and considering the fact that these earlier experiments involved drier vegetation, they extend the range of the current results. Some variability is to be expected since the planting densities were different on the various days.

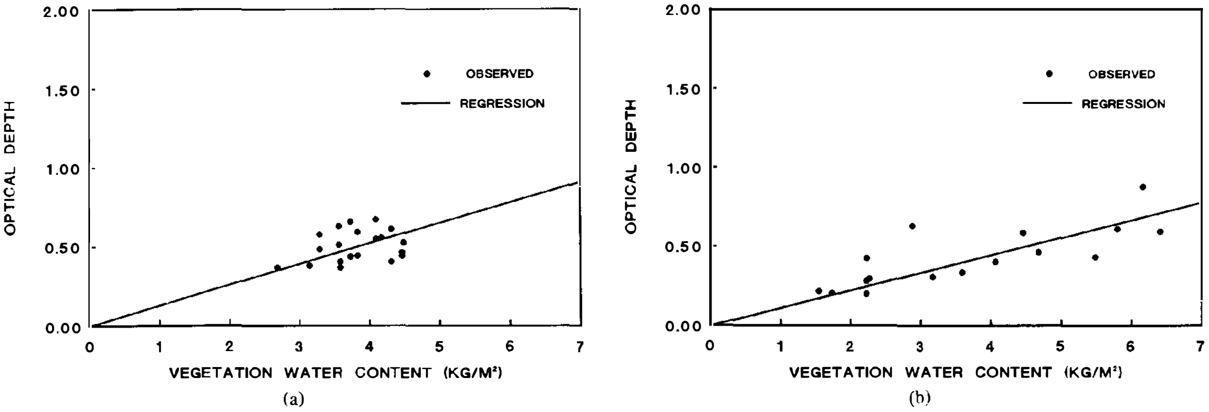
V. Summary

Vegetation must be considered when using microwave data to estimate surface soil moisture. Correction algorithms should consider both the physics involved and the practical problem of how the necessary data will be obtained. A relatively simple correction model was evaluated in this study using data collected in controlled condition experiments utilizing truck-mounted passive microwave radiometers. The results support previous research on the effects of wavelength and vegetation water content. Algorithm tests using a crop-type single-scattering albedo estimate and vegetation water



(a) (b)

Fig. 2. Optical depth versus vegetation water content for 5 GHz *H* polarizations. (a) Corn; and (b) soybeans.



(a) (b)

Fig. 3. Optical depth versus vegetation water content for the 1.4 GHz *H* polarization 10° angle. (a) Corn; and (b) soybeans.

TABLE I
ESTIMATES FOR MODEL INCLUDING α

Band	Crop	Coefficient (b)	Standard error of estimate for τ
L	corn	0.130	0.101
L	soybeans	0.111	0.126
L [3]	corn	0.095	
L [3]	soybeans	0.131	
C	corn	0.174	0.093
C	soybeans	0.438	0.390

TABLE II
ESTIMATES FOR MODEL WITHOUT α

Band	Crop	Coefficient (b)	Standard error of estimate for τ
L	corn	0.115	0.072
L	soybeans	0.086	0.122
L*	various	0.110	---
C	corn	0.156	0.078
C	soybeans	0.288	0.262
C*	various	0.150	---

*from [1] after adjusting for factor of 2 in the definition of b.

content (both of which can be determined using remotely sensed data) with *L*-band microwave data show that this approach can be used to account for the vegetation effect.

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