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Estimation of crop variables using bistatic scatterometer data and artificial neural network trained by empirical models

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ABSTRACT

Multi-temporal and multi-angular bistatic scatterometer measurements were carried out on two similar specially prepared kidney bean crop beds at two frequencies (6 GHz and 10 GHz) for like polarizations (HH- and VV-). The present study describes the estimation of crop variables and crop covered soil moisture of kidney bean crop using artificial neural network (ANN). The suitable configurations of bistatic scatterometer system were found at 10 GHz, 50° incidence angle for the estimation of kidney bean crop variables and 6 GHz, 20° incidence angle for the estimation of crop covered soil moisture at VV-polarization by linear regression analysis. Two artificial neural network models namely ANN-I and ANN-II were developed for the estimation of crop variables and crop covered soil moisture of kidney bean crop, respectively. The observed data set (scattering coefficients, crop variables and crop covered soil moisture) of first crop bed of kidney bean was used as a reference data set for developing empirical models. The training of the ANN-I model was done using 95 data set generated through empirical models consistent with the age of the kidney bean crop. The ANN-II was trained using the scattering coefficients and crop covered soil moisture of reference crop bed. The trained ANN-I and ANN-II models were tested by the observed data set of second kidney bean crop bed. The estimated values by ANN-I and ANN-II were found very close to the observed values of the crop variables and crop covered soil moisture of second kidney bean crop bed.

1. Introduction

The estimation of crop variables at various growth stages of kidney bean crop is the key factor for the monitoring of kidney bean crop. The leaf area index is highly related to a variety of canopy processes and directly quantifies the plant canopy structure. The crop height is an important crop variable to provide the direct information about the plant type and yield potential. The chlorophyll content is an important crop variable to monitor the crop photosynthesis ability and growth status. Thus, the estimation of crop growth variables like vegetation water content, leaf area index, plant height and chlorophyll content at its different growth stages may be used for the crop monitoring. The nature of angular variation of scattering coefficient at different growth stages of crop may be analyzed for studying the crop signature.

The application of microwave remote sensing to study the earth resources is becoming more popular by using scatterometer (Bouman, 1991; Toure et al., 1994; Wegmuller, 1990), airborne (Ferrazzoli et al., 1999, 1997; Hoogeboom, 1983; Macelloni et al., 2001; Taconet et al., 1994) and space born (Cookmartin et al., 2000; Le Toan et al., 1997; Moran et al., 1998; Wegmuller and Werner, 1997) in the field of agriculture.

One of the most important applications of microwave remote sensing is to monitor the crop/vegetation by investigating the scattering mechanism of microwave with the crop variables and their estimation at several growth stages. The phenomenon of scattering mechanism between vegetation constituents and the microwave is very complex for the analysis in the remote sensing. Scattering mechanism depends on the system properties and target physical properties like plant type, plant structure and plant morphology (leaf area index, plant water content, leaf length, leaf width, number of stems, plant height, etc.). Inoue et al. (2002) have investigated the microwave backscattering response of leaf area index and biomass for the entire growth period of paddy crop at five frequencies (Ka, Ku, X, C, and L) for all polarizations (HH, VH, HV, and VV) in the angular range of incidence angles 25–55°.

The backscattering coefficient is found enough sensitive to detect thin rice seedlings just after transplanting at higher frequency (Ka-, Ku-, and X-bands) and higher incidence angles. Taconet et al.

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(1994) investigated the radar backscattering of wheat field by an airborne scatterometer at C- and X-bands for both like polarizations (HH- and VV-). The magnitude of backscattering coefficient is attenuated by both the underlying soil moisture and vegetation constituents at low frequency (C-band). However, the magnitude of backscattering coefficients at high frequency (X-band) is influenced mostly by the vegetation canopy.

Various modeling approaches have been developed for better understanding of interactions of microwave signals with vegetated and forest targets (Stiles et al., 1993; Ulaby et al., 1981, 1982). Karam et al. (1992) has developed a scattering model for layered vegetation based on an iterative solution of the radiative transfer equation up to the second order to account for multiple scattering within the canopy and between the ground and the canopy. This model is designed to operate over a wide frequency range for both deciduous and coniferous forest parameter measurements with good results at both like and cross polarizations.

These microwave vegetation models are very difficult to solve inversion problem and understand the microwave response of individual crop variables for a particular crop. It requires large number of input data sets. Nowadays, several researchers have shown great interest toward artificial neural networks as a model free tool in the field of remote sensing for the estimation of crop variables (Jiang et al., 2004; Stankiewicz, 2006; Wilkinson et al., 1995). It is pursuit of worthy to combine an artificial neural network with appropriate vegetation electromagnetic models (physical, semi-empirical or empirical) for the estimation crop variables. Del Frate et al. (2003) have trained two artificial neural network algorithms by physical vegetation model for retrieving the soil moisture and vegetation variables of wheat crop.

In the present study, the observations were taken on specially prepared two parallel crop beds of kidney bean at an interval of three days. The first crop bed was considered as a reference field to develop empirical models. These developed empirical models were used to generate the training data sets consistent with age of kidney bean crop for the training of ANN-I model. Hence, the prior knowledge about the soil surface properties and vegetation status are not required for the training of artificial neural network used for the estimation of crop variables of kidney bean crop. The observed data set (scattering coefficients and kidney bean crop variables) of the second crop bed were used for the testing of ANN-I model. The training of ANN-II model was done with the observed data set (scattering coefficients and crop covered soil moisture) of the reference crop bed. The testing of ANN-II model was done by using the data sets acquired from the second crop bed of kidney bean.

The objectives of the present study were (i) to determine the suitable bistatic scatterometer configuration for the accurate estimation of soil moisture and crop variables of kidney bean crop, (ii) to establish a reliable relationship between the bistatic scattering coefficient (σ^0) and crop variables to generate large input data set by empirical models for the training of ANN and (iii) to solve the inversion problem for the estimation of crop variables and crop covered soil moisture.

2. Method and observations

2.1. Bistatic scatterometer and crop variables measurements

Two outdoor kidney bean crop beds of size 3×3 m^2 were specially prepared besides the department of Physics, Indian Institute of Technology (BHU), India, for the bistatic measurements at various growth stages of kidney bean crop. The bistatic scatterometer experiment was conducted by changing the incidence angle of the receiving and transmitting antenna from 20° to 70° at azimuthal angle $\phi = 0$ in the specular direction. The footprint of antenna beam covered the areas of the kidney bean crop bed under study between 0.2247 m^2 and 5.655 m^2 in the angular range of incidence angle 20–70°. The specifications and schematic representation of bistatic scatterometer set-up used for our investigation are shown in Table 1 and Fig. 1 respectively.

Two pyramidal horn antennas were mounted (one on transmitting side and other on receiving side) on a wooden platform which facilitates to vary the height and incidence angle. The distance between antenna and the center of the target was chosen to work in the far-field region in order to minimize the near-field interactions. The polarization of the radiated signal was changed by using 90°E–H twists (the plane of electric and magnetic fields). The bistatic scatterometer system was calibrated before and after bistatic scatterometer measurement for the crop kidney bean.

Crop kidney bean is taken as the broad leaf crop. It attained maximum average height of 49 ± 2 cm in our crop bed during the entire observations. The maturity age of crop was found to be 97 ± 5 days after the date of sowing.

The vegetation water content (VWC) of the plant is the total water content in the plant constituents. The plant density was calculated in the kidney bean crop bed. Three quadrant of 1 m^2 area were selected at the different location of kidney bean crop bed. The kidney bean plant (sample) was taken from each quadrant at each time of the bistatic scatterometer measurements. The leaves and stalks of the samples were dried in an oven at 100 °C for 24 h. The samples were weighted before and after drying in kg. The VWC of kidney bean crop was calculated by multiplying the plant density with the difference between the weights of wet and dry samples. The leaf area index (LAI) is defined as the ratio of total upper leaf surface of the crops divided by the surface area of the land on which the crop are grown. An instrument ACCUPAR LP-80 was used to measure LAI (Cohen et al., 1997; Delalieux et al., 2008). The intensity of sunlight, direction of sun rays, calibration of the instrument, number of activated sensors and the alignment of sensor strip play major role during the measurement of LAI. LAI is dimensionless; however, it is presented in the units of m^2/m^2.

The chlorophyll content (CC) of a crop is an important parameter for sustaining the healthy life of any crop. The SPAD value of the plant was measured by using an instrument SPAD-502 Plus (Coste et al., 2010; Cramer et al., 2001; Ling et al., 2011). The SPAD value is the relative index of chlorophyll content in the plant.

The soil samples were taken at the depth of 5 cm for the gravimetric soil moisture content measurement from three different locations of the kidney bean crop bed. The soil samples were dried in an oven at 100 °C for 12 h. The soil samples were weighted

Table 1
Bistatic scatterometer system specifications.

Parameter		X-band	C-band
Frequency (GHz)		10 ± 0.05	6 ± 0.05
Beam width	E plane (°)	17.3118	22.0833
	H plane (°)	19.5982	19.0476
Band width (GHz)		0.8	0.5
Antenna gain (dB)		20	25
Cross-polarization isolation (dB)		40	40
Polarization modes		Horizontal transmit–horizontal receive (HH) Vertical transmit–vertical receive (VV)	
Antenna type		Dual-polarized pyramidal horn	
Calibration accuracy (dB)		1	
Platform height (meter)		3	
Incidence angle (°)		20° (nadir)–70°	
Measurement interval		20 min	