CHAPTER 6

ESTIMATION OF CORN CROP GROWTH PARAMETERS BY WATER CLOUD MODEL USING SAR DATA

6.1 INTORDUCTION

The estimation of crop growth parameters is very important in agricultural management and in yield forecasting. LAI is an essential indicator of agricultural productivity and a critical parameter in crop growth models. The information from different satellites can be exploited to assist in estimating important crop growth parameters such as LAI, biomass and PH (Jiao et al., 2010). Several optical remote sensing data have been used for the estimation of LAI (Baret and Guyot, 1991; Chen and Cihlar, 1996; Colombo et al., 2003). However, the crop growth and yield monitoring activities based on optical imagery are vulnerable because of data gaps during crop growth stages due to unfavourable atmospheric conditions (Jiao et al., 2010).

SARs are unaffected by atmospheric haze, clouds and rain (Chakraborty et al., 2005). SAR response is dependents upon the sensor configuration including incidence angle, frequency and polarization and on the target parameters such as canopy size, water content, and geometry of the canopy components (Jiao et al., 2010; Prasad, 2011). Shorter SAR wavelengths such as C-band (~6 cm) interact mainly with the top part of the canopy layers (Ulaby et al., 1984). Inoue et al. (2002) studied $\sigma°$ response of the biophysical parameters of paddy rice using multi-frequency (Ka, Ku, X, C, and L band) data. LAI was found best correlated with HH and cross-polarization $\sigma°$ at C-band, conversely, LAI and biomass were poorly correlated with the higher frequency (Ka, Ku, and X) bands.

The WCM is not a theoretically complex model it can be inverted easily and applied to a different vegetation types with reasonable outcomes (Attema and Ulaby, 1978). It is a semi-empirical model and is widely used to retrieve crop growth parameters (Ulaby et al., 1984; Champion et al., 2000). Prevot et al. (1993) investigated the applicability of WCM for the estimation of LAI and soil moisture. WCM was also calibrated for the retrieval of LAI of corn crop from C-band SAR data at VV polarization (Beriaux et al., 2013). In the case of sparse vegetation the SAR signal depends on the vegetation characteristics and soil backscattering signal which includes direct part and component attenuated by vegetation layer (Svoray and Shoshany, 2002). This study proposes a semi-empirical WCM to estimate LAI and LWAI using C-band Sentinel-1A observations and field measurements.

6.2 MATERIALS AND METHODOLOGY

6.2.1 Corn crop growth stages

The different crop growth stages of the corn crop are shown in the Figure 6.1.

Figure 6.1 Different growth stages of the corn crop

The growth cycle of corn crop depends on the different varieties of the crop and environmental conditions. It is very essential to know about the different growth stages of the crop for the understanding of the microwave response of crop growth parameters. Generally, corn crop is not grown in the month of January and February in the North India. However, at some places in Varanasi it was grown in the month of January and February particularly for the research purposes.

6.2.2 Leaf area index measurements

In-situ measurements of LAI values were collected from 15 January to 20 April 2016 in Varanasi district, India. An instrument namely LAI-2200C Plant Canopy Analyzer was used for the corn crop LAI measurements. LAI was found increasing at the earlier growth stages; however it was decreases at the ripening stage. Total 64 samples of the LAI were collected in the subplots of 1 m^2 area in the 100 m x 85 m corn crop field. The in-situ measurements were done carefully at the same date of satellite data acquisition.

6.2.3 Satellite data collection and processing

Sentinel-1A microwave satellite with frequency 5.405 GHz at C-band was launched on 3 April 2014 by the ESA. The SAR images from 15 January 2016 to 20 April 2016 of Interferometric Wide (IW) swath at VV polarization were downloaded (https://scihub.copernicus.eu/dhus/#/home) for the full growth period of corn crop. The SNAP software version 1.1.1 particularly Sentinel-1 toolbox (S-1 TBX) downloaded (http://step.esa.int/main/download/) was used for the processing of the SAR data-sets. The features of the Ground Range Detected (GRD) Sentinel-1A images are described in the Table 6.1.

Table 6.1 Sentinel-1A satellite data features

Satellite and band	Date of acquisition	Mode	Pass direction	Polarization	Product type	Resolution (m x m)	Product level
Sentinel-1A (SAR-C)	15/01/2016	IW	Ascending	VV	GRD	5x20	L1
	01/02/2016	IW	Ascending	VV	GRD	5x20	L1
	25/02/2016	IW	Ascending	VV	GRD	5x20	L1
	03/03/2016	IW	Ascending	VV	GRD	5x20	L1
	20/03/2016	IW	Ascending	VV	GRD	5x20	L1
	27/03/2016	IW	Ascending	VV	GRD	5x20	L1
	13/04/2016	IW	Ascending	VV	GRD	5x20	L1
	20/04/2016	IW	Ascending	VV	GRD	5x20	L1

6.2.4 Water cloud model

WCM (Attema and Ulaby, 1978) for the given incidence angle θ_i can be described by the relation given in the equation 6.1.

$$\sigma^{\circ}_{pp} = \sigma^{\circ}_{veg} + \sigma^{\circ}_{veg+soil} + L^2\sigma^{\circ}_{soil} \quad (6.1)$$

where σ°_{pp} = co-polarized total backscattering coefficient

σ°_{veg} = backscatter contribution of the vegetation cover

$\sigma^{\circ}_{veg+soil}$ = multiple scattering involving vegetation elements and the soil surface

σ°_{soil} = backscatter contribution of the soil surface

L^2 = two-way vegetation attenuation

The second term in the equation 6.1 represents the interaction of the incident radiation between the vegetation and underlying soil. In the case of copolarized radiation the interaction is not a dominating factor and thus can be neglected (Dobson and Ulaby, 1986; Prevot et al., 1993). Ulaby et al. (1978) concluded that backscatter from the bare soil is a linear function of the surface soil moisture for a given radar configuration. The modified equation is given in 6.2.

$$\sigma^{\circ}_{pp} = \sigma^{\circ}_{veg} + L^2\sigma^{\circ}_{soil} \quad (6.2)$$

$$\sigma^{\circ}_{veg} = AV_1 \cos\theta_i(1 - L^2) \quad (6.3)$$

$$L^2 = \exp(-2BV_2 \sec\theta_i) \quad (6.4)$$

$$\sigma^{\circ}_{soil} = C + DM_v \quad (6.5)$$

The equation 6.6 is obtained by substituting the expression of σ°_{veg}, L^2 and σ°_{soil} into equation 6.2.

$$\sigma^{\circ}_{pp} = AV_1 \cos\theta_i \,(1 - \exp(-2BV_2 \sec\theta_i))\text{+}\exp(-2BV_2 \sec\theta_i)\,(C + DM_v) \qquad (6.6)$$

where A and B are the fitting parameters, V_1 and V_2 are the vegetation descriptors, θ_i is the angle of incidence, C and D are the bare soil parameters and are obtained with linear model fitting, M_v is the volumetric soil moisture

The vegetation descriptors V_1 and V_2 are defined as V_1 = LAI and V_2 = LWAI

LWAI = LAI * W (6.7)

Moisture content (W) of the plant = $\frac{W_W - W_d}{W_w}$

where W_W is the freshly plucked weight of vegetation samples and W_d is the dried weight of vegetation samples

6.2.5 Estimation of crop growth parameters

The parameters C and D of the WCM were obtained using least square regression between σ° and soil moisture measured for the bare soil field (Graham and Harris, 2002; Kumar et al., 2015). Out of 64 samples, the 44 samples were used in developing the model and the 20 samples were used to validate the model. After obtaining soil parameters C and D, the corresponding vegetation parameters A and B were estimated from the image and field observed data of the vegetated and bare soil locations. The model parameters A and B can be estimated using non-linear least squares optimization technique coupled with WCM. The values of model parameters A, B, C and D and the observed σ°, LAI, SM and LWAI were put into the model described in equation (6.6) (Prevot et al., 1993; Graham and Harris, 2002; Kumar et al., 2015). The estimated values of the model parameters A, B, C, and D and the observed σ° at different growth stages were put into the WCM and it was inverted to retrieve LAI and LWAI by running the same non-linear least squares optimization routine (Prasad, 2011).

6.3 RESULTS AND DISCUSSION

This optimization method was used to estimate LAI and LWAI, which were found highly correlated with σ°. The values of the LAI, LWAI were estimated by putting the values of the observed and calculated values of σ° into a non-linear least squares optimization equation. The values of σ° were found to increase with the LAI of the corn crop. LAI was found independent on soil moisture when LAI > 3. The effect of soil moisture was found at the early growth stages. Figure 6.2 presents a comparison between observed and modelled LAI at VV polarization.

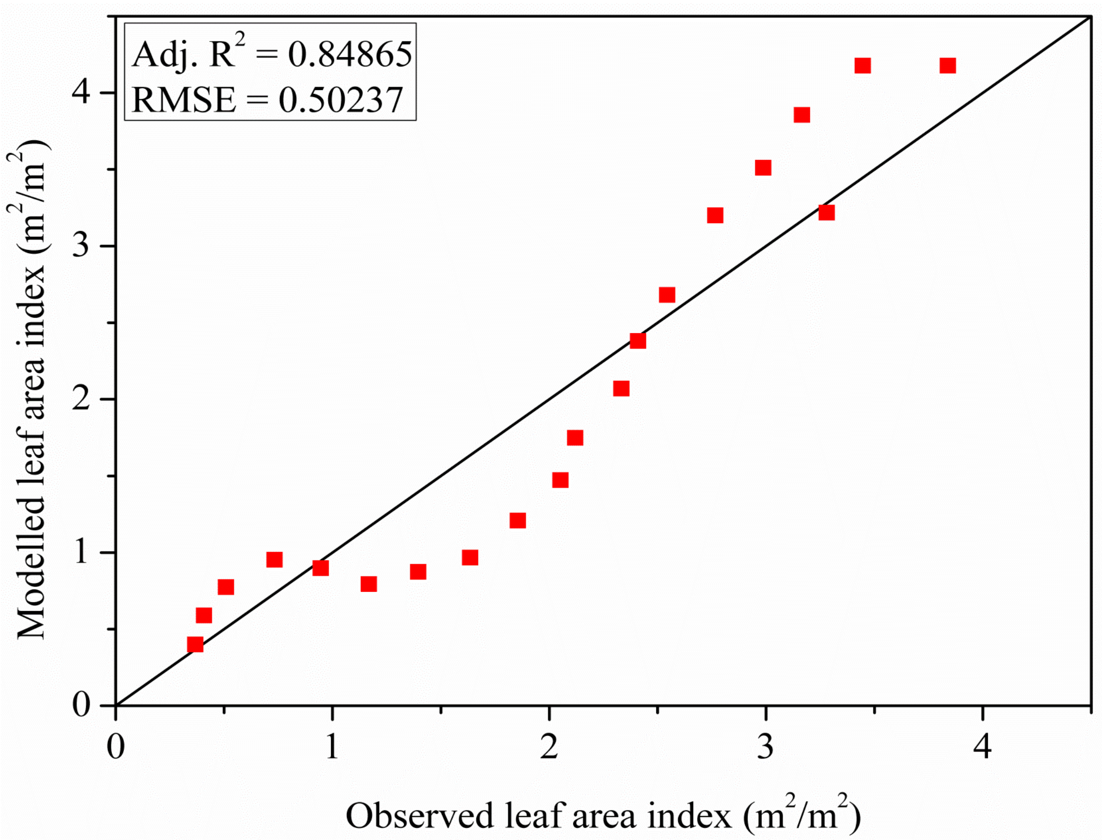

Figure 6.2 Comparison between observed and modelled leaf area index at VV polarization

The observed values of LAI were found close to the estimated values as indicated by the high value of correlation (adj. R^2 = 0.84865) observed in the investigation. Several researchers have reported that microwaves interact strongly with the vertical stem, LAI and LWAI at an incidence angle of 45° for different crops like wheat, barley, soybean, oilseed rape and lady's fingers (Wigneron et al., 1999, Cookmartin et al., 2000, Prasad, 2009).

The good adj. R^2 = 0.73014 was found in the estimation of LWAI. However this value of adj. R^2 was found lesser than the adj. R^2 = 0.84865 of the LAI. The relation between the observed and the modelled values of the LWAI at the later stages were not found better because of several factors as the changing geometry of crop and less water present at crop at the ripening conditions. The random scattering occurred at the later growth stages was one of the reasons for getting the poor correlation between observed and modelled LWAI. Figure 6.3 shows the observed and modelled LWAI at VV polarization.

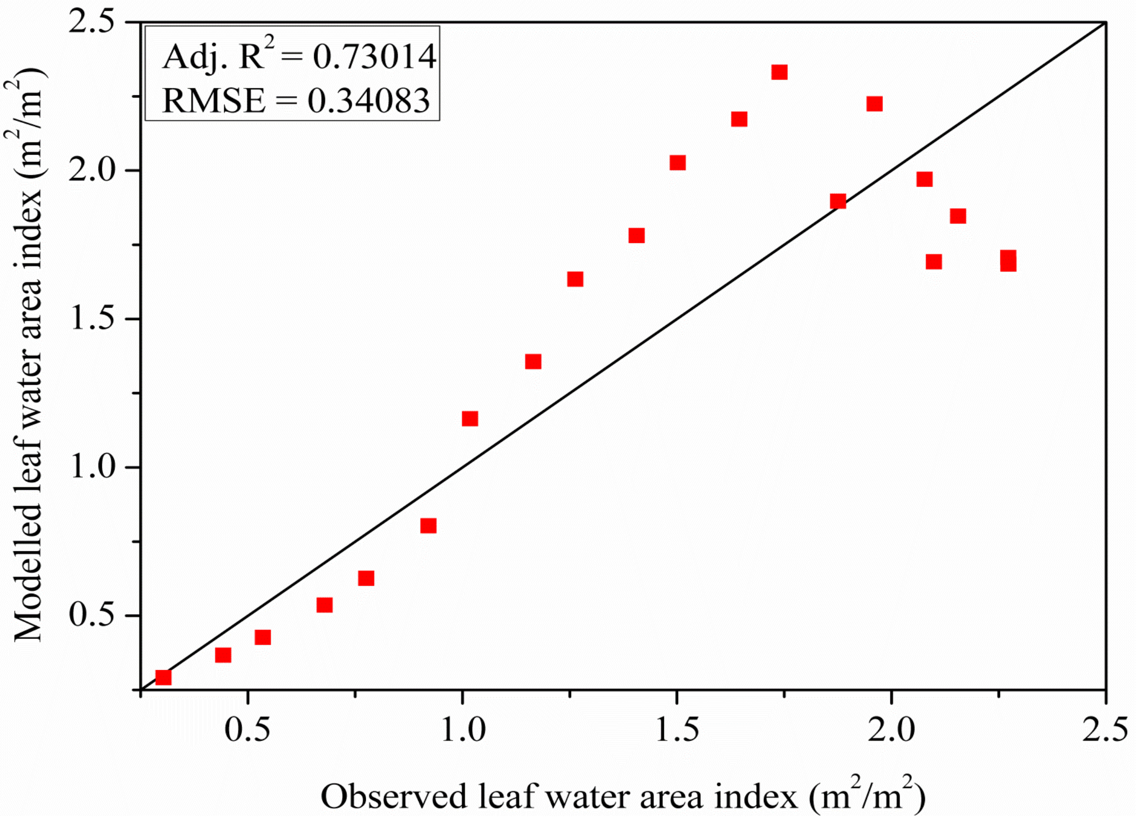

Figure 6.3 Comparison between observed and modelled leaf water area index at VV polarization

6.4 CONCLUSION

Temporal variation in σ° was found highly correlated with the LAI and LWAI. The retrieval values of LAI and LWAI by the inversion of WCM were found close to the observed values. During the later growth stages, the σ° was found dominated by an increase in LAI because the crop also gets volumetrically dense with the age. The dominant contribution to total σ° comes from volume scattering of vegetation when LAI > 3, whereas soil contributes to σ° when LAI < 2. The dependence of σ° on soil moisture was found to be negligible when LAI > 3. Studying the interaction mechanism of a particular crop using Sentinel-1A data is useful for a better understanding of the scattering behaviour of a target under observation.