ANALYSIS OF POLARIMETRIC SCATTERING IN A PADDY RICE CANOPY USING AN AUTOMATIC RADAR SCATTEROMETER SYSTEM

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Abstract—**The objectives of this study were to investigate the temporal behavior of radar backscatter from paddy rice using a polarimetric scatterometer system and analyze scattering characteristics of paddy rice growth using decomposition method. We obtained the data continuously in every 10 minutes by using an L-, C- and X-band automatic radar scatterometer measurement system. The season-long backscattering coefficients from transplanting to harvesting stages were compared with rice growth parameters. Backscattering coefficients of all bands with polarization gradually increased in accordance with rice growth and decreased owing to the reduction of LAI and fresh biomass. In the decomposition, single bounce was the dominant factor at all stages and in all bands and Beta component of pauli decomposition in L-band significantly appeared after heading stage. It found that L-band related to double bounce scattering according to rice growth.**

Keywords-Radar scatterometer; decomposition; backscattering coefficients; rice growth; polarization

I. INTRODUCTION

Rice is one of the major crops in Korea and primary food source for more than half of the world's population. Microwave remote sensing can help monitor the land surface water cycle and crop growth. Previous studies have been carried out to interpret crop biophysical parameters by using satellite SAR sensors [1]–[3]. A ground-based polarimetric scatterometer has an advantage for continuous crop using multi-polarization and multi-frequencies and various incident angles have been used extensively in a frequency range expanding from L-band to Ka-band [4]–[5]. Many plant parameters such as leaf area index (LAI), biomass and plant height are highly correlated with backscattering coefficients, as well as radar frequency and polarization. Among SAR techniques, Polarimetric SAR (POLSAR) has potential to understand the land cover more effectively from a viewpoint of scattering on the surface. The decomposed components may provide scattering information about vegetation, such as density and height of paddy rice on the water surface. The methodology to decompose multi-polarized scattering into components has been developed. For example, Freeman [6] proposed three-component decomposition to estimate into volume scattering, surface scattering and double bounce scattering components. Lee and Pottier [7] proposed pauli decomposition for scattering characters. In this paper, we constructed an L-, C- and X-band automatic scatterometer system and analyzed scattering characteristics of paddy rice over the whole period of rice growth from transplanting to harvesting. We examined the scattering characteristics of paddy rice using pauli decomposition method.

II. MATERAL AND METHOD

A ground-based polarimetric scatterometer operating at multiple frequencies can continuously monitor the crop conditions. The measurement was conducted at an experimental field located in National Academy of Agricultural Science (NAAS), Suwon, Korea. The rice cultivar was a kind of Japonica type, called Chuchung. The size field was about 660m^2. Growth data for the rice canopy, such as LAI, fresh and dry biomass and plant height, were acquired once every week by destructive sampling in order to radar backscattering coefficients.

Polarimetric observations at X-, C- and L-band were made every 10 minutes to study the effect of weather conditions at various rice growing stages on the microwave observations. The polarimetric scatterometer consists of a vector network analyzer (20 MHz ~ 20 GHz), a microwave switch, radio frequency cables, power unit and a personal computer (Table 1). The center frequency of the three antennas was designed to replicate existing radar satellites; L-band: Advanced Land Observing Satellite (ALOS) PALSAR, C-band: ENVISAT and RADARSAT, and X-band: TerraSAR-X, COSMO-SkyMed and KOMPSAT-5 COSI.

Table 1. Specification of the microwave scatterometer system.

Parameters		X-Band	C-Band	L-Band
Frequency (GHz)		9.65±0.5	5.3±0.3	1.27±0.06
Beam width	11.15-15.72	35.11-41.73	35.11-41.73	11.15-15.72
	14.62-19.36	40.88-49.22	40.88-49.22	14.62-19.36
Number of Frequency Points		1601	801	201
Antenna Type		Dual polarimetric square horn		
Antenna Gain (dB)		22.4	20.1	12.4
Slant Range Resolution (m)		0.15	0.25	1.25
Band Width (MHz)		1000	600	120
Wavelength (m)		0.031	0.056	0.23
Polarization		HH, HV, VH, VV		
Incident Angle (°)		40		
Platform Height (m)		4.20		
Measurement interval		10 minutes		
Sweep Time (s)		1.8	0.9	0.225

All the components were installed inside an air-conditioned shelter to maintain constant temperature and humidity during the data acquisition period (Fig. 1). Polarimetric scatterometer provides a time domain radar return from a target as a fully polarimetric (HH, HV, VH, VV) amplitude and phase data. The system is calibrated using a calibration kit (SmA, 85052D). Backscattering coefficients were calculated by applying radar equation [8].

Fig. 1. Photos of an automatic scatterometer system: (left photo) The system was installed in a shelter with L, X and C-band antennas (from left to right) looking down the rice paddy field at 40° incidence angle; (right photo) The RF system inside the shelter is composed of a notebook computer, a vector network analyzer, a microwave switch, power unit, and an air conditioner.

Pauli decomposition of polarimetic scattering data is one of the simplest but intuitive methods to separate backscattering mechanisms by single bounce, double bounce and volume scattering. The pauli decomposition of the scattering matrix is often employed to represent all the polarimetric information in a single SAR image. The polarimetric information of $[S]$ could be represented by the combination of the intensities $|S_{hh}|^2$, $|S_{vv}|^2$ and $2|S_{hv}|^2$ in a single RGB image.

Given a measured scattering matrix $[S]$, Pauli decomposition is expressed by Pottier [7].

$$[s] = \begin{bmatrix} s_{hh} & s_{hv} \\ s_{hv} & s_{vv} \end{bmatrix} = \alpha [s]_a + \beta [s]_b + \gamma [s]_c \tag{1}$$

Where

$$\alpha = \frac{s_{hh} + s_{vv}}{\sqrt{2}} \tag{2}$$

$$\beta = \frac{s_{hh} - s_{vv}}{\sqrt{2}} \tag{3}$$

$$\gamma = \sqrt{2} s_{hv} \tag{4}$$

[S]a, [S]b, [S]c is the Pauli basis. α value represents single bounce scattering, β value means double bounce scattering and γ value stand for volume scattering.

III. RESULTS AND DISCUSSION

We investigated relation daily backscattering data with rice growth parameters. In all bands, VV polarization backscattering were higher than HH polarization backscattering until about at DAT 28 (effective tillering stage) and then was reversed (crossover) (Fig. 2). HH polarization backscattering coefficients at L-band increased monotonously with biomass growth until heading stage (DAT 84) thereafter slowly decreased (Fig. 2-a). Temporal changes in backscattering coefficients at C-band during the growing period were shown as Fig. 2-b. The HH polarization backscattering coefficients increased as growth until around heading stage (DAT 84) and then decreased until harvesting stage (DAT 147). VV polarization backscattering coefficients higher than HH- and cross polarization backscattering coefficients before effective tiller stage (DAT 28). Difference in backscattering coefficients between HH and VV polarization at C-band was less than that of L-band after heading stage and cross polarization backscattering coefficients steadily decreased after heading stage. Figure 2-c shows temporal behavior of backscattering coefficients at X-band with rice growth. Backscattering coefficients of range at X-band were lower than those of L, C-band. X-band appeared dual peak during rice growth stage (peak1: DAT 68, peak 2: DAT 137).

Since backscattering coefficients are related with physical parameters of the target such as structure and dielectric constants, the meaningful information could be obtained by a correlation analysis between backscattering coefficients and plant variables. Table 2 shows correlation analysis between backscattering coefficients in X-, C-, L-band and rice growth parameters. The highest correlation coefficients for fresh biomass were found at HH polarization in L-band (r=0.97) and LAI was highly correlated with HH- and cross-polarization in L-, C-band (over r=0.90). Plant height was correlated with HH polarization in L-band (r=0.88). Backscattering coefficients in X-band were weakly correlated with LAI and fresh biomass. Grain weight and grain water content highly correlated with backscattering coefficients with VV polarization in X-band(r=0.94, r=0.93, respectively). This result suggests that high frequency microwave may barely penetrate the rice canopy and backscattering coefficients contain little information on volumetric characteristics such as biomass and LAI.

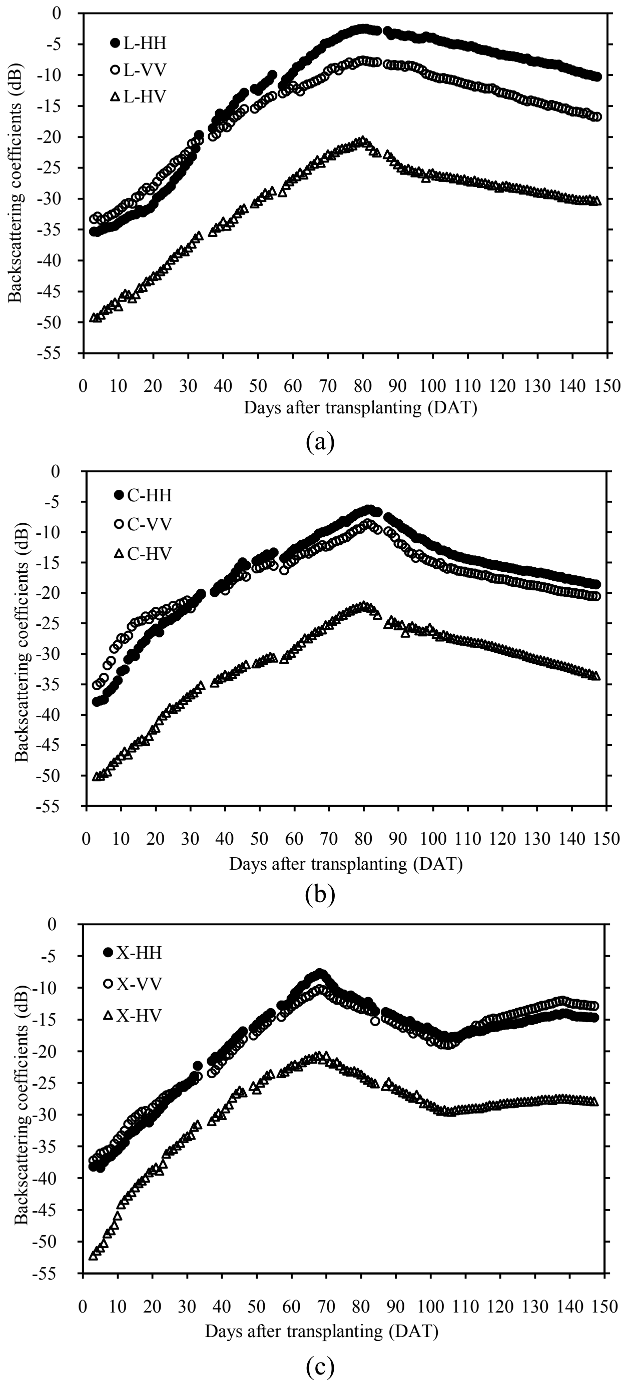
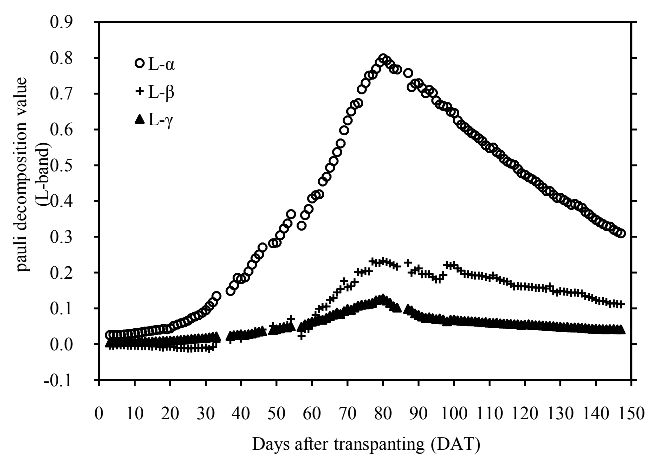


Fig. 2. Daily backscattering coefficients of HH, VV and HV channels during the whole rice-growth period in (a) L-band, (b) C-band and (c) X-band.

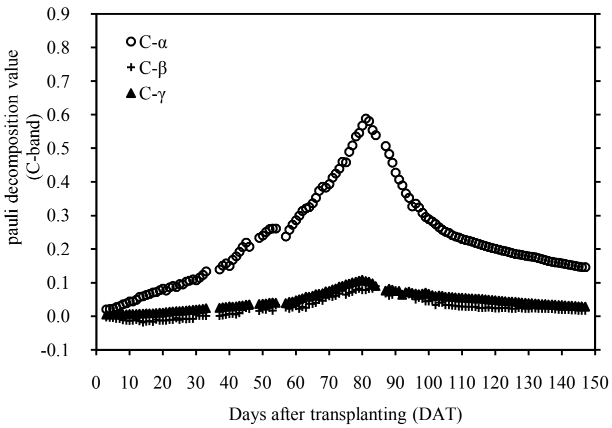
Table 2. Correlation coefficients between backscattering of X, C, L-band in full-polarization and various rice growth parameters.

Growth Data	X-band			C-band			L-band		
	HH	VV	HV	HH	VV	HV	HH	VV	HV
Total Fresh weight	0.81	0.73	0.83	0.84	0.75	0.88	0.97	0.87	0.89
Leaf Area Index	0.72	0.66	0.68	0.90	0.86	0.91	0.96	0.84	0.91
Plant Height	0.72	0.63	0.79	0.73	0.60	0.77	0.88	0.80	0.79
Grain Dry Weight	0.81	0.94	0.70	-0.62	-0.60	-0.64	-0.57	-0.53	-0.62
Grain water Content	0.84	0.93	0.78	-0.58	-0.60	-0.51	-0.60	-0.58	-0.54

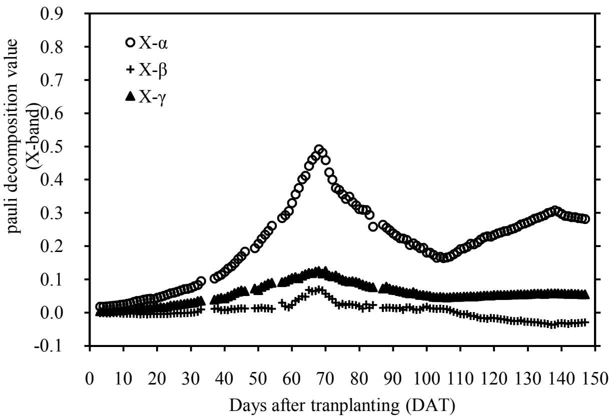
We analyzed scattering characteristics of paddy rice using pauli decomposition method. In case of rice plants, the single bound dominates when radar is reflected mainly from the canopy top. Double bounce comes from the radar signal reflected at water surface and then bounced again at the stems while volume scattering occurs when rice plant is fully grown and the penetration of microwave through the canopy is allowed. Among them, single bounce is the dominant factor for all stage and in all bands and pauli decomposition value was the highest in the L-band. In the L-band, Beta value was higher than gamma value after panicle formation stage (DAT 62). Double bounce from flooded water and stems dominates L-band backscattering over volume scattering from leaves due to higher penetration of longer wavelength into rice canopy, while volume scattering dominates X-band. Double bounce and volume scattering approximately equals in C-band.



(a)



(b)



(c)

Fig. 3. Components of Pauli decomposition (α, β and γ) in (a) L-band, (b) C-band and (c) X-band.

IV. CONCLUSIONS

Backscattering coefficients of rice crop were investigated with an automatically-operating ground-based scatterometer. We examined the temporal variations of the backscattering coefficients of the rice crop at L, C and X-band during a rice growth period. Backscattering coefficients of all bands with polarization gradually increased in accordance with rice growth data and decreased owing to the reduction of LAI and fresh biomass. X-band backscattering coefficients observed dual-peak characteristics during rice growth stage and grain water content closely related to X-band backscattering. We also analyzed the relationship between backscattering coefficients with each band and rice growth parameters. Biomass was most highly correlated with the L-band, and with the C-band next, while it was poorly correlated with the X-band. LAI was closely correlated with HH polarization in L-band. Grain weight was correlated with backscattering coefficients with VV polarization in X-band and it was sensitive to grain maturity at near harvesting season. This tendency corresponds with the theory that X-band microwave is reflected mainly at the top of canopy while L-band microwave can go through the vegetation. Polarimetric decomposition of paddy data such as single, double and volume scattering effectively extracted the scattering information.

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