Radar Backscattering Measurements of Paddy Rice Field using Multifrequency(L, C and X) and full Polarization

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Abstract-The objective of this study is to measure backscattering coefficients of paddy rice using L, C, X-bands scatterometer system during a rice growth period and relationship between backscattering coefficients and rice growth variables with full polarization and various angles. The measurement was conducted at an experimental field located in National Institute of Agricultural Science and Technology (NIAST), Suwon, Korea. The rice cultivar was a kind of Japonica type, called chuchung. The scatterometer system consists of dual-polarimetric square horn antennas, HP8720D vector network analyzer (20MHz ~ 20GHz), RF cables, and a personal computer that controls frequency, polarization and data storage. The backscattering coefficients were calculated by applying radar equation for the measured at incidence angles between 20° and 60° for four polarization (HH, VV, HV, VH), respectively, and compared with rice growth data such as plant height, stem number, biomass, dry weight and LAI that were collected at time of each scatterometer measurement simultaneously.

Keyworlds—Backscattering coefficients; Scatterometer system; network analyzer; polarization; rice growth data

1. INTRODUCTION

Rice is one of the major crops in Korea. In spite of its importance as a food source, there have been few attempts to monitor rice growth and study backscattering characteristics with a microwave instrument from space-ground platform. Microwave radar can penetrate cloud cover regardless of weather conditions and it can be used day and night. Especially a ground-based polarimetric scatterometer has advantage of monitoring crop conditions continuously using full polarization and various frequencies. Many plant parameters such as leaf area index (LAI), biomass, plant height are highly correlated with backscattering coefficients and according to frequency, polarization between plant parameters and backscattering coefficients was different (Ulaby, 1984; Bouman, 1991). Le Toan et al. (1997) showed the potential SAR backscatter data for rice crop monitoring based on both satellite and ground based scatterometer measurements. Hong et al. (2000) analyzed RADARSAT data (5.3 GHz, hh-polarization, and incidence angles between 36° and 46°) for monitoring the rice growth in Korea. In this study, we examine the temporal behaviour of the radar backscatter from rice crops during the growth period at multi-frequency (L, C, X-band) with angular response.

2. MATERIAL AND METHOD

The test site was located in NIAST experimental field (37° 15’ 28.0” N, 126° 59’ 21.5” E) Suwon, Korea. The rice cultivar was a kind of Japonica type, called chuchung. The size field was about 660m^2. Table 1 show the scatterometer system specification.

Table 1. Specification of the scatterometer system

Specification	L-Band	C-Band	X-Band
Center Frequency	1.27 GHz	5.3 GHz	9.65 GHz
Bandwidth	0.12 GHz	0.6 GHz	1 GHz
Number of Frequency Points	201	801	1601
Antenna Type	Dual polarimetric horn	Dual polarimetric horn	Dual polarimetric horn
Antenna Gain	12.4dB	20.1dB	22.4dB
Polarization	HH, VV, HV, VV	HH, VV, HV, VV	HH, VV, HV, VV
Incident Angle	20° ~ 60°	20° ~ 60°	20° ~ 60°
Platform Height	4.16m	4.16m	4.16m

The system mainly composed of dual-polarimetric square horn antennas, vector network analyzer (VNA), RF cables, and a personal computer. The VNA-based polarimetric scatterometer operates in a stepped-frequency sweep mode.

Polarimetric scatterometer provides a time domain radar return from a target as a fully polarimetric (HH, HV, VH, VV) amplitude and phase data. Changing of frequency bands, polarization of antennas and data storage can be controlled by the computer. The system is calibrated using a calibration kit (3.5mm, 85052D). Radar backscattering measurements began on 15 May 2007 before the transplanting with HH, HV, VH, VV polarizations and at incidence angle of 20 ~ 60°. Growth data for the rice canopy, such as LAI, wet and dry biomass and plant height, were acquired at time of each scatterometer measurement simultaneously. Backscattering coefficients were calculated by applying radar equation. It defined as the following expression.

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 R^4} \quad (1)$$

Where G_t and G_r are the gains of the gains of transmitting and receiving antennas in the direction of the target, λ is the wavelength, and σ is the RCS of the target.

Backscattering coefficients of each bands calculated as the follow expression.

$$L-band: \sigma^{o}(dB) = 20\log U + 21.35(dB) + 30\log R + 10\log\cos\theta \quad (2)$$

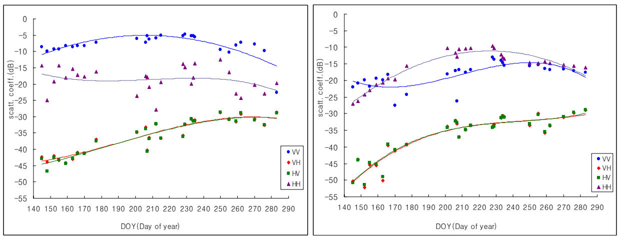
$$C-band: \sigma^{o}(dB) = 20\log U + 30.27(dB) + 30\log R + 10\log\cos\theta \quad (3)$$

$$X-band: \sigma^{o}(dB) = 20\log U + 32.21(dB) + 30\log R + 10\log\cos\theta \quad (4)$$

3. RESULTS AND DISCUSSION

Backscattering coefficients of paddy fields at L-band, C-band and X-band range from about -55dB ~ 0dB, -50dB ~ +5dB, -50dB ~ -10dB, respectively. At large incident angles, range of backscattering coefficients higher than that of small incident angle. In three bands, vv-polarized backscattering coefficients were higher than hh-polarized backscattering coefficients during rooting stage (mid-June) and hh-polarized backscattering coefficients were higher than vv- and hv/vh-polarized backscattering coefficients after panicle initiation stage (mid-July). Figure 1 shows the temporal variations of the backscattering coefficients of the rice crop at L-band after transplanting, at various incidence angles. VV-polarized backscattering coefficients higher than hh- and hv/vh-polarized backscattering coefficients during rooting stage (mid-Jun). HV/VH polarized backscattering coefficients increased towards the heading stage (mid-Aut) and thereafter saturated, again increased near end of the season.

Incident angle: 30 Incident angle: 40



Incident angle: 50 Incident angle: 60

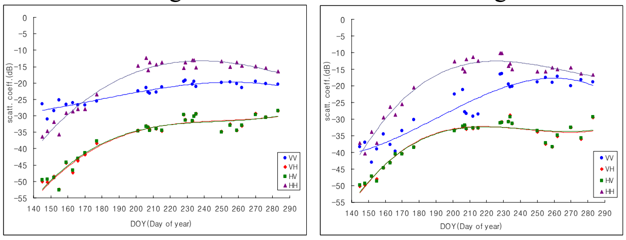
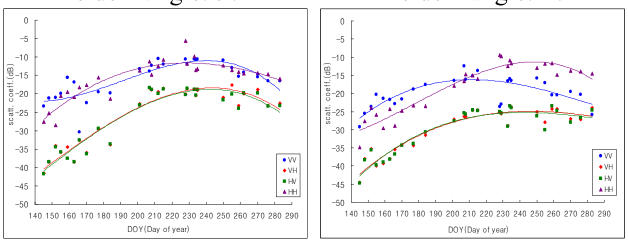


Fig. 1. Temporal variations of backscattering coefficients at polarization and incident angle 30°~60° for the L-band.

Changes of backscattering coefficients at C-band during growing periods were shown in Figure 2. The HH-polarized backscattering coefficients at all incident angles (except 20°) increase as growth advanced and saturate at the ripening stage.

Incident angle: 30 Incident angle: 40



Incident angle: 50 Incident angle: 60

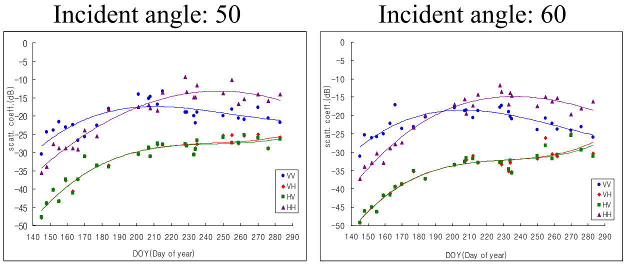


Fig. 2. Temporal variations of backscattering coefficients at polarization and incident angle 30°~ 60° for the C-band.

Figure 3 shows change in backscattering coefficients at C-band with growth. Backscattering coefficients of range at X-band lower than that of L-, C-band. HH-, VV-polarized σ° steadily increased toward panicle initiation stage and thereafter decreased, again increased near end of the season. This dual-peak trend was clearer larger incident angles. larger incident angles (over 50°) at cross-polarized σ° was similar phenomenon. Biomass was decreased and heads of the canopy were easily show, so X-band as high frequency sensitive to heading or grain maturity during the post heading stage. It is generally understood that higher frequencies, like the Ku- and X-bands, are dominated by canopy scattering, while lower frequencies, like the L-, and P-bands, have dominant canopy or significant soil backscatter contributions to total backscatter (Brisco & Brown, 1998).

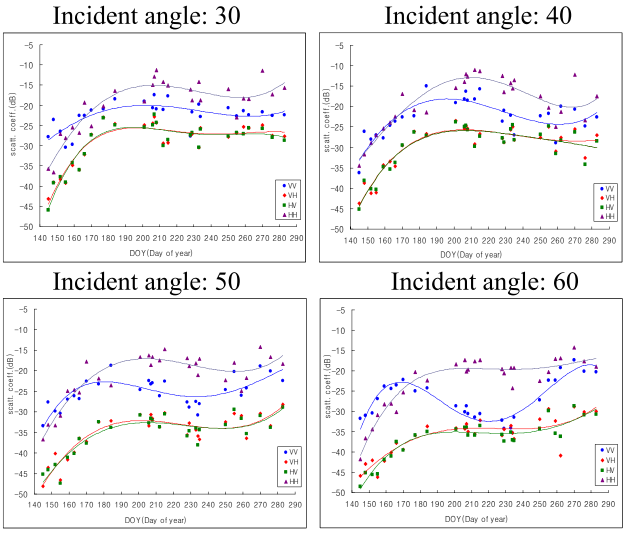


Fig. 3 Temporal variations of backscattering coefficients at polarization and incident angle 40, 50, 60° for the X-band.

Next, we conducted a correlation analysis between the backscattering coefficients under each band and plant variables such as LAI and biomass. Table 2 shows relationship between backscattering coefficients in L-band and rice growth parameters. The highest correlation coefficients for LAI were found in incident angle 50° with hh-polarization. The VV polarization was less well correlated with LAI the HH- and cross-polarization. Biomass was higher correlated with over 50° with hh and cross-polarization.

Table 2. Relationship between backscattering coefficients in L-band and plant variables.

	VV		HH		HV/VH	
Incident angle	LAI	Biomass (g/m^2)	LAI	Biomass (g/m^2)	LAI	Biomass (g/m^2)
20	-0.81^{**}	-0.90^{***}	-0.20^{ns}	-0.37^{ns}	0.38^{ns}	0.29^{ns}
25	-0.20^{ns}	-0.37^{ns}	0.44^{*}	0.38^{ns}	0.85^{**}	0.81^{**}
30	0.28^{ns}	0.15^{ns}	-0.38^{ns}	-0.42^{*}	0.77^{**}	0.85^{**}
35	-0.63^{*}	-0.58^{*}	0.25^{ns}	0.31^{ns}	0.71^{**}	0.80^{**}
40	0.58^{*}	0.70^{*}	0.73^{**}	0.76^{**}	0.81^{**}	0.86^{***}
45	0.78^{**}	0.87^{***}	0.89^{***}	0.92^{***}	0.91^{***}	0.90^{***}
50	0.63^{*}	0.75^{**}	0.94^{***}	0.97^{***}	0.86^{***}	0.90^{***}
55	0.62^{*}	0.75^{**}	0.93^{***}	0.95^{***}	0.88^{***}	0.92^{***}
60	0.74^{**}	0.81^{**}	0.88^{***}	0.89^{***}	0.90^{***}	0.91^{***}

Correlation analysis between backscattering coefficients in C-band with plant variables was shown in table 3. LAI was highly correlated with the C-band HH- and cross-polarization at incident angle over 45°. Inoue (2002) found a very high correlation between the C-band backscattering at 25° HH, 25° cross, 35° cross with LAI during rice growth seasons. In our experiments, however, backscattering coefficients at small incident angles (below 35°) in HH and VV polarization was low correlation with LAI. This discrepancy might be attributed to differences in crop structure, backscattering situation (roughness, moisture), weather condition and crop types.

Table 3. Relationship between backscattering coefficients in C-band and plant variables.

	VV		HH		HV/VH	
Incident angle	LAI	Biomass (g/m^2)	LAI	Biomass (g/m^2)	LAI	Biomass (g/m^2)
20	-0.74^{**}	-0.84^{**}	-0.67^{*}	-0.76^{**}	0.67^{*}	0.74^{**}
25	0.72^{**}	0.75^{**}	0.48^{*}	0.46^{*}	0.92^{***}	0.96^{***}
30	0.78^{**}	0.82^{**}	0.83^{**}	0.84^{**}	0.92^{***}	0.95^{***}
35	0.70^{*}	0.67^{*}	0.84^{**}	0.90^{***}	0.91^{***}	0.95^{***}
40	0.55^{*}	0.50^{*}	0.87^{**}	0.92^{***}	0.93^{***}	0.95^{***}
45	0.64^{*}	0.56^{*}	0.91^{***}	0.93^{***}	0.88^{***}	0.92^{***}
50	0.76^{**}	0.74^{**}	0.90^{***}	0.93^{***}	0.85^{**}	0.88^{***}
55	0.70^{*}	0.68^{*}	0.95^{***}	0.96^{***}	0.83^{**}	0.86^{***}
60	0.46^{*}	0.44^{*}	0.94^{***}	0.95^{***}	0.83^{**}	0.88^{***}

Fig 4 shows correlation analysis between backscattering coefficients in L-, C-, X-band and grain weight. X band backscattering coefficients close correlation with the grain weight (ultimately the grain yield). The best correlations were for X-band VV polarization at incident angle 50°(r=0.93) and X-band 55°, 60° VV was also closely correlated. Contrarily, other bands were poorly correlated with the grain weight at all incident angles (except L-VV, 45°). The HH polarization and small incident angle were less well correlated with grain weight, while VV-, cross-polarization were highly correlated in X-band. Rice head (upper surface of the canopy) is the major scattering for high-frequency microwaves.

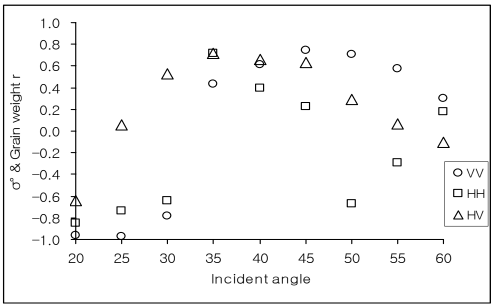


Fig 4(a). Correlation between σ° in L-band and grain weight.

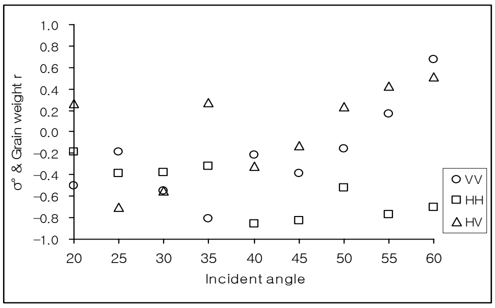


Fig 4(b). Correlation between σ° in C-band and grain weight.

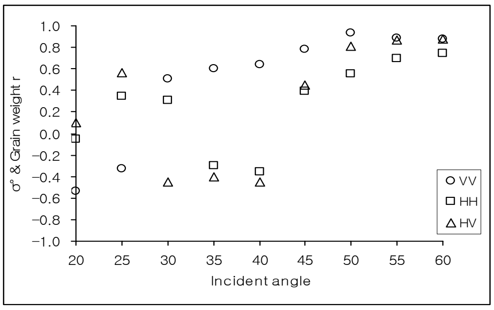


Fig 4(c). Correlation between σ° in X-band and grain weight.

In summary, the lower frequency bands, such as L and C, were closely related with the mass information of the whole canopy such as LAI, biomass, while the higher-frequency band, such as X, is poorly correlated with them but closely correlated with the other variables such as head weight. This result is mainly attributed to the difference in relative size of wavelength and the penetration depth of each band. HH polarization responds more with vertical structure of rice plants than the others. Another trend was that the VV polarization was less well correlated with plant variables than the other polarizations in most cases. This may be interpreted by the process that HH- and cross-polarizations penetrate more effectively into canopies and consequently have greater seasonal changes than the VV does.

4. CONCLUSION

Backscattering coefficients of rice crop were investigated with a ground-based scatterometer. The measurements were carried out at L-, C-, X-band with full polarizations and different incident angles. The temporal variations of the backscattering coefficients of the rice crop at L-, C-, X-band during rice growth period. At large incident angles, range of backscattering coefficients higher than that of small incident angle. VV polarization backscattering coefficients higher than HH-polarized backscattering coefficients in early rice growth stage. HH polarization backscattering coefficients higher than VV polarization backscattering coefficients after panicle initiation stage. We conducted the relationship between backscattering coefficients with L-, C-, X-band and rice growth parameters. Biomass was correlated with L-band hh-polarization at a large incident angle. LAI was highly correlated with C band hh- and cross-polarizations. Grain weight was correlated with backscattering coefficients with X-band VV polarization at a large incidence angle. X-band was sensitive to grain maturity during the post heading stage.

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6. REFERENCES

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