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Monitoring the Spectral Back Scattering of Lodged Dry-direct Seeded Rice by Temporal Sentinel - I Data

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ABSTRACT

The study was conducted from June, 2020 to January, 2021 in two villages namely; Chinna Tandrapadu and Mandoddi of Ieeja Mandal, Gadwal district, Telangana, India to assess the lodged crop using the sentinel-I data with two polarizations and two cross polarisations backscatter values. The two major methods were direct Seeding and transplanting. In direct-seeded rice, seeds were directly sown in the field, the plants did not have deep root penetration and were susceptible to crop lodging, a major problem during the flowering and grain-filling stages, leading to crop loss and damage during the monsoon season. The area under the crop was estimated using remote sensing, which provided real-time, reliable, and quick information. Microwave data with its longer wavelength (1 mm to 100 mm) could penetrate through clouds and other atmospheric particles, and hence its usage in monitoring rice ecosystems gained importance. In this study, Sentinel-1A images were utilized for analysis. The multi-temporal C-band dual-polarization VV, VH, and their combinations VV VH^{-1} and VH VV^{-1} backscattering values were studied throughout the crop growth period. The backscatter values obtained from the crop during the growth stages were analyzed using the paired t-test. It revealed that the flowering, dough, and maturity stages were the periods when the lodged crop could be discriminated from the unlodged crop at the VV and VH polarizations. The band cross-combinations VV VH^{-1} and VH VV^{-1} were not able to discriminate the lodged crop.

KEYWORDS: Crop lodging, direct seeded rice, microwave, sentinel, transplanted

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Lodging is displacement of the stems from their upright position, either due to stem collapse or the failure of the root-soil anchoring system (Pinthus, 1974, Huang et al., 2016). It is a major issue in cereal crops (wheat, rice, barley, maize, and oats) significantly reducing yields (Islam et al., 2007; Shah et al., 2017). The major factors that cause lodging are strong winds, heavy rainfall, and improper farming practices such as heavy use of fertilizers and high planting densities, which exacerbate lodging (Quang Duy et al., 2004, Yang et al., 2015). According to studies by Berry and Spink (2012) and Berry et al. (2013), yield losses in oilseed rape and cereals in the UK can amount to as much as 75% if lodging takes place close to the grain-filling stage. The economic losses resulting from oilseed and wheat in years with significant lodging are expected to be £64 million and £105 million, respectively. Beyond just lowering yield, lodging also results in deterioration of grain quality, structural damage to plants, and physiological disruptions (Li et al., 2022; Zhang et al., 2023). For this reason, it is crucial for stakeholders including farmers, agronomists, insurers, and legislators to evaluate the danger of lodging and its consequences (Holzman et al., 2018; McCarty et al., 2021).

Over the past few decades, the use of sensors and Remote sensing (rs) technologies has grown significantly and their application in agriculture monitoring is increasing steadily (McNairn et al., 2009; Guo et al., 2021). RS technologies are used in many areas of agriculture in crop acreage estimation, drought assessment and crop condition assessment, the also provide high spatial data and temporal data that provides near realtime estimation (Guan et al., 2022; Zhang et al., 2020). RS is also becoming a crucial tool for assessing crop lodging, which can help improve crop production and loss estimates (Chauhan et al., 2018; Rabieyan et al., 2023).

There are many studies that are addressing the crop lodging issues by many agronomists and plant physiologists in development of models to simulate seasonal lodging risk (Baker et al., 2014; Sposaro et al., 2010 ; Canisius et al., 2018; Zhao et al., 2020) and also to understand the morphological traits associated with lodging (Kong et al., 2013). Traditionally, assessments of lodging have been made using field-based techniques, such as visual inspections, in which the severity and angle of lodging are used to establish a score (Wang et al., 2024; Biswal et al., 2022). Nevertheless, small-scale coverage, high labour costs, difficult accessibility, and bad weather sometimes pose limitations to these conventional methods (Ajadi et al., 2020; Zhang et al., 2024).

Changing climatology and ecologies have reflected its responses on vegetation by alterations to its biophysical and biochemical properties, either immediately or gradually (Hong et al., 2007; McNairn et al., 2009). Numerous studies have established and documented the use of RS technology to monitor such changes (Montes et al., 2020; Liu et al., 2023; Jun et al., 2018).). These methods can also be extended to extract information related to crop lodging. Rs technologies uses two key components: (i) understanding specific plant traits that either make crops prone to lodging or help in assessing its occurrence, and (ii) selecting appropriate modelling techniques. This information aids in predicting lodging risk and mapping its severity.RS-based lodging assessments have utilized data from passive sensors to detect lodging (e.g., lodged vs. non-lodged crops) (Liu et al., 2014). The major constraint, however is availability of cloud free data throughout the crop growing season is not possible the use of microwave data in the assessment of the crop lodging proven to be best and provides accurate information (Canisius et al., 2018; Cable et al., 2014). The current study utilises the sentinel-I data with two polarizations and two cross polarisations backscatter values to assess the lodged crop.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted from June, 2020-January, 2021 in Gadwal district of Telangana, in two villages: Chinna Tandrapadu and Mandoddi located in Ieeja mandal at 16.01590E and 77.684810N (Lat/Long). The villages predominantly cultivate rice using two established methods: dry-direct seeded rice (DDSR) and transplanted rice (TP-R). The primary sources of irrigation is rajolibanda lift irrigation project. As these villages are located at the tail end of the irrigation system, farmers in the region largely adopt the dry direct-seeded rice method due to its water and time-saving advantages for rice establishment (Figure 1).

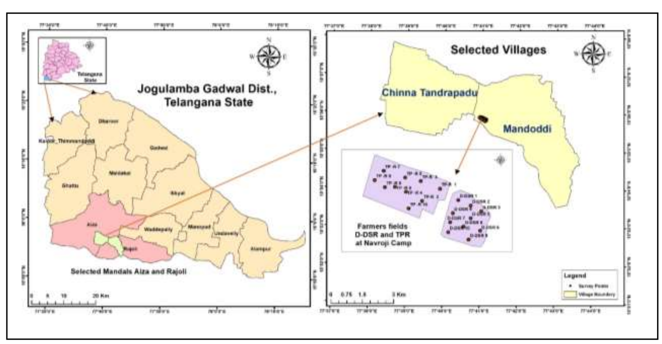

Figure 1: Location of the study area

2.2. Satellite images and ancillary data

The satellite data used for the study was Sentinel-1, which was downloaded from the European Space Agency. The data was pre-processed for all corrections, including speckle filtering, terrain corrections, and radiometric corrections.

Then, a logarithmic transformation was performed to extract the backscatter values from the images. The images are freely accessible from the Copernicus Open Access Hub. A total of 17 Level-1 GRD (Ground Range Detected) images with normalized backscatter over the study area were used in the study. The ancillary data included the crop calendar for rice cultivation in the area. Specifically, direct seeding starts during the early *kharif* season, i.e., from mid-June to mid-July, when the crop is sown during the early showers of the monsoon in the southern part of India. Transplanting of rice begins with the release of water from the irrigation project, i.e., from mid-August to mid-September.

2.3. Collection of ground truth data

The cropped area of the study location was surveyed to identify rice-growing regions. Ten random points with severe lodging were selected for data collection and for extracting backscatter values to facilitate detailed analysis in the study.

2.4. Statical analysis

Backscatter values were extracted from both lodged and unlodged crops and analyzed using Microsoft Excel 2019. A paired t-test with equal variance was performed, as the backscatter values were obtained from the same crop under different treatments.

2.5. Rain fall data

The total actual rainfall received during the crop growth period was 1078 mm, compared to the normal rainfall of 486 mm for the region, resulting in excess rainfall during this period. The total number of rainy days was 62. Rainfall is a major factor influencing crop lodging, particularly during October when the crop is at the flowering stage. Rainfall during this period contributed to significant lodging in the region (Figure 2).

2.6. Methodology

The downloaded images were pre-processed, and layer stacking was performed. Spectral signatures were then extracted from the images and subjected to statistical analysis to discriminate the lodged crops. A detailed methodology flowchart is provided in Figure 3.

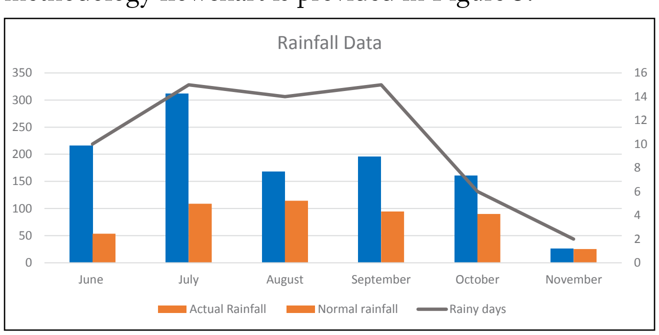

Figure 2: Graph of rainfall during the crop growth season

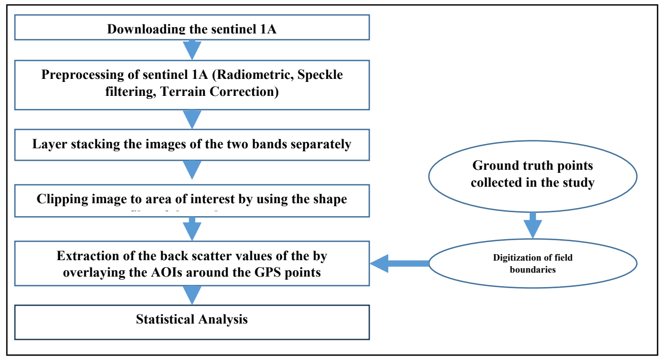

Figure 3: Detailed methodology flowchart

3. RESULTS AND DISCUSSION

3.1. Extraction of spectral signatures

The 17 images were layer-stacked to create a composite. GPS data were overlaid, and areas of interest (AOIs) were selected. From these AOIs, backscatter values were extracted, and the mean backscatter of the four polarizations was analyzed (Kumar et al., 2021). To align with the crop growth period, the stages of crop development were carefully matched. The major lodging problem in rice was observed during the flowering and grain-filling stages, which required proper monitoring to effectively discriminate the crop. Both spectral and temporal profiles showed significant differences.

The characterization of lodged crops was based on two key assumptions:

• Lodged crops lying flat on the ground scatter more backscatter compared to standing crops due to significant loss of backscatter caused by internal collisions within the plant canopy.

• Differences in the angle of incidence and angle of reflectance resulted in variations in backscatter values across all four polarizations.

3.2. Temporal profiling of the back scatterings from VV and VH polarisations

The rice crop exhibited temporal variability in VH polarization backscatter values throughout the growing season (Table 1). The highest backscatter value, -16.8 dB, was observed during the land preparation stage, and in later stages, the dB values ranged from -17 to -19.8 dB for the unlodged crop. Significant variability in backscatter values was observed during flowering, dough, and maturity stages, with the values for lodged crops being notably higher, ranging from -15.8 to -13.9 dB (Figure 4). These higher values may be attributed to reduced absorption from the crop canopy and increased backscatter from the target.

The crop also displayed significant temporal variability in backscatter values in VV polarization throughout the growth season (Table 2). For the unlodged crop, backscatter

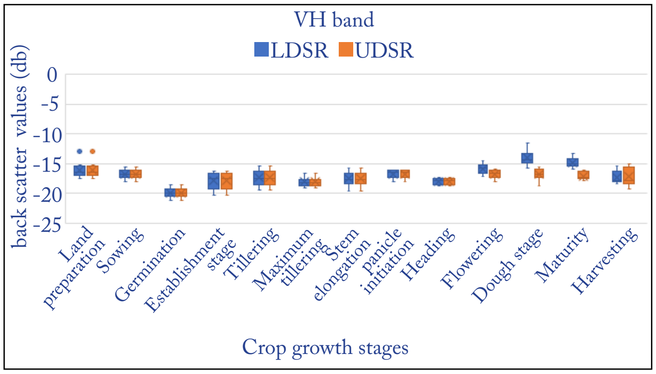

Figure 4: Graph showing spectral backscattering values

values ranged from -8.9 to -13.4 dB. The backscatter values decreased during crop growth but began to increase at maturity. Significant differences were found in backscatter values during the flowering, dough, and maturity stages for VV polarization (Figure 5). In contrast, for lodged crops, backscatter values were higher during the flowering, dough, and maturity stages, ranging from -9.2 to -12.2 dB. This increase in backscatter values can be attributed to the reduced obstacles for reflectance caused by the lodging.

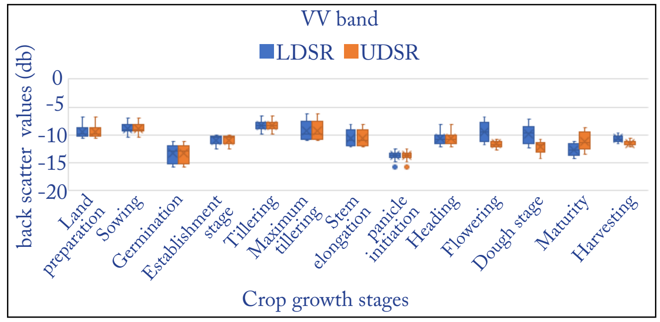

Figure 5: Graph showing spectral backscattering values

3.3. Temporal profiling of the back scatterings cross polarisations VV VH^{-1} and VH VV^{-1}

The temporal backscatter in both cross-polarizations did not show any significant difference between lodged and unlodged rice crops. However, there was an increasing trend in backscatter during the crop growth, reaching its peak during the tillering stage, followed by a reduction at maturity in the case of VV and VH^{-1} (Table 3). Similarly, a reduction in backscatter values was observed with crop growth in the VV and VV^{-1} bands, with an increase in backscatter values

Table 1: Spectral back scattering values of VH band

VH	Lodged direct seeded rice					
Sl. No.	land preparation	Sowing	Germination	establishment stage	Tillering	Maximum tillering
LDSR1	-16.366	-15.945	-18.901	-18.821	-17.142	-18.005
LDSR2	-15.28	-16.521	-20.162	-16.742	-17.744	-18.391
LDSR3	-12.866	-17.954	-20.194	-17.651	-17.923	-18.773
LDSR4	-15.447	-16.845	-19.722	-17.211	-16.122	-16.643
LDSR5	-17.515	-17.223	-20.481	-20.223	-18.496	-18.707
LDSR6	-16.561	-17.742	-21.246	-19.164	-18.606	-18.002
LDSR7	-15.452	-15.627	-19.271	-16.948	-15.423	-16.869
LDSR8	-17.376	-17.207	-19.7	-19.437	-19.405	-18.59
LDSR9	-16.584	-16.788	-20.667	-16.219	-16.282	-19.018
LDSR10	-16.749	-16.056	-18.567	-16.315	-16.481	-17.863
Un-lodged direct seeded rice						
UDSR1	-16.366	-15.945	-18.901	-18.821	-17.142	-18.005
UDSR2	-15.28	-16.521	-20.162	-16.742	-17.744	-18.391
UDSR3	-12.866	-17.954	-20.194	-17.651	-17.923	-18.773
UDSR4	-15.447	-16.845	-19.722	-17.211	-16.122	-16.643
UDSR5	-17.515	-17.223	-20.481	-20.223	-18.496	-18.707
UDSR6	-16.561	-17.742	-21.246	-19.164	-18.606	-18.002
UDSR7	-15.452	-15.627	-19.271	-16.948	-15.423	-16.869
UDSR8	-17.376	-17.207	-19.7	-19.437	-19.405	-18.59
UDSR9	-16.584	-16.788	-20.667	-16.219	-16.282	-19.018
UDSR10	-16.749	-16.056	-18.567	-16.315	-16.481	-17.863

VH	Lodged direct seeded rice						
Sl. No.	Stem elongation	panicle initiation	Heading	Flowering	Dough stage	Maturity	Harvesting
LDSR1	-19.622	-17.634	-17.625	-16.421	-14.43	-15.667	-17.87
LDSR2	-16.641	-16.073	-18.48	-16.948	-14.387	-15.372	-17.77
LDSR3	-16.577	-16.068	-18.021	-14.596	-11.499	-14.759	-18.354
LDSR4	-16.914	-17.116	-18.69	-15.831	-13.546	-15.229	-16.387
LDSR5	-15.66	-16.405	-18.781	-14.536	-12.249	-13.277	-18.288
LDSR6	-17.604	-17.171	-17.697	-15.648	-14.174	-15.87	-17.947
LDSR7	-17.785	-16.126	-17.293	-17.051	-15.265	-15.328	-15.875
LDSR8	-18.657	-16.567	-17.793	-15.674	-13.696	-13.385	-15.439
LDSR9	-17.562	-16.224	-17.814	-16.235	-14.695	-14.96	-17.717
LDSR10	-18.188	-17.93	-17.311	-15.519	-15.765	-14.423	-17.917
Un-lodged direct seeded rice							
UDSR1	-19.622	-17.634	-17.625	-15.996	-15.922	-17.249	-18.383
UDSR2	-16.641	-16.073	-18.48	-17.053	-18.747	-17.388	-17.741
UDSR3	-16.577	-16.068	-18.021	-16.199	-15.632	-17.717	-18.348
UDSR4	-16.914	-17.116	-18.69	-16.588	-17.209	-17.787	-17.93
UDSR5	-15.66	-16.405	-18.781	-15.969	-16.012	-16.031	-15.602
UDSR6	-17.604	-17.171	-17.697	-16.451	-16.388	-16.258	-15.475
UDSR7	-17.785	-16.126	-17.293	-17.216	-17.135	-17.241	-16.094
UDSR8	-18.657	-16.567	-17.793	-17.437	-16.215	-16.16	-14.949
UDSR9	-17.562	-16.224	-17.814	-16.369	-17.395	-17.521	-18.041
UDSR10	-18.188	-17.93	-17.311	-18.092	-17.28	-17.177	-19.281

Table 2: Spectral back scattering values of VV band

VV	Lodged direct seeded rice					
Sl. No	land preparation	Sowing	Germination	establishment stage	Tillering	Maximum tillering
LDSR1	-6.769	-9.281	-11.451	-10.069	-6.82	-9.656
LDSR2	-9.848	-9.517	-12.223	-10.287	-8.489	-10.702
LDSR3	-10.096	-10.538	-15.261	-10.256	-8.659	-9.681
LDSR4	-8.265	-8.018	-11.29	-11.561	-8.101	-7.816
LDSR5	-9.89	-9.266	-15.743	-10.281	-9.964	-9.942
LDSR6	-10.027	-8.27	-13.782	-11.545	-8.963	-11.098
LDSR7	-8.883	-8.707	-12.317	-10.758	-6.715	-6.261
LDSR8	-10.283	-8.917	-15.373	-12.481	-8.303	-11.097
LDSR9	-10.715	-9.29	-13.53	-11.733	-8.878	-10.229
LDSR10	-10.187	-7.08	-12.479	-10.303	-8.14	-7.212
Un-lodged direct seeded rice						
UDSR1	-6.769	-9.281	-11.451	-10.069	-6.82	-9.656
UDSR2	-9.848	-9.517	-12.223	-10.287	-8.489	-10.702
UDSR3	-10.096	-10.538	-15.261	-10.256	-8.659	-9.681

Table 2: Continue...

VV	Lodged direct seeded rice					
Sl. No	land preparation	Sowing	Germination	establishment stage	Tillering	Maximum tillering
UDSR4	-8.265	-8.018	-11.29	-11.561	-8.101	-7.816
UDSR5	-9.89	-9.266	-15.743	-10.281	-9.964	-9.942
UDSR6	-10.027	-8.27	-13.782	-11.545	-8.963	-11.098
UDSR7	-8.883	-8.707	-12.317	-10.758	-6.715	-6.261
UDSR8	-10.283	-8.917	-15.373	-12.481	-8.303	-11.097
UDSR9	-10.715	-9.29	-13.53	-11.733	-8.878	-10.229
UDSR10	-10.187	-7.08	-12.479	-10.303	-8.14	-7.212

Table 2: Continue...

VV	Lodged direct seeded rice						
Sl. No	Stem elongation	Panicle initiation	Heading	Flowering	Dough stage	Maturity	Harvesting
LDSR1	-10.532	-13.383	-10.165	-9.902	-12.413	-13.602	-10.4655
LDSR2	-10.169	-13.7	-10.114	-9.181	-11.959	-14.23	-10.8405
LDSR3	-11.918	-12.532	-9.747	-7.954	-7.171	-12.811	-10.5985
LDSR4	-9.086	-12.85	-8.121	-8.644	-8.361	-11.597	-9.68485
LDSR5	-12.179	-13.79	-10.549	-6.849	-9.393	-11.674	-10.905
LDSR6	-12.043	-14.863	-11.818	-11.598	-11.458	-13.677	-11.6432
LDSR7	-8.24	-13.818	-11.323	-10.145	-8.63	-12.391	-9.991
LDSR8	-11.703	-15.818	-11.297	-6.858	-9.126	-11.232	-11.0776
LDSR9	-11.343	-13.631	-11.444	-11.193	-9.847	-12.681	-11.2445
LDSR10	-9.105	-13.434	-12.173	-11.77	-10.587	-13.005	-10.6338
Un-lodged direct seeded rice							
UDSR1	-10.532	-13.383	-10.165	-11.197	-11.699	-13.444	-10.5954
UDSR2	-10.169	-13.7	-10.114	-10.947	-14.262	-12.426	-12.1714
UDSR3	-11.918	-12.532	-9.747	-12.451	-13.734	-13.037	-11.7435
UDSR4	-9.086	-12.85	-8.121	-12.722	-12.236	-12.084	-11.5393
UDSR5	-12.179	-13.79	-10.549	-11.981	-12.838	-8.821	-11.7618
UDSR6	-12.043	-14.863	-11.818	-10.869	-11.581	-9.315	-11.7087
UDSR7	-8.24	-13.818	-11.323	-11.721	-12.015	-10.3	-10.9378
UDSR8	-11.703	-15.818	-11.297	-11.689	-11.064	-9.558	-11.3455
UDSR9	-11.343	-13.631	-11.444	-11.201	-10.841	-10.95	-11.9713
UDSR10	-9.105	-13.434	-12.173	-11.933	-11.58	-11.762	-11.7784

Table 3: Spectral backscattering of VV VH-1 band

VV VH-1	Lodged direct seeded rice					
Sl. No	land preparation	Sowing	Germination	establishment stage	Tillering	Maximum tillering
LDSR1	9.597	6.664	7.451	8.752	10.321	8.35
LDSR2	5.432	7.004	7.939	6.455	9.255	7.69
LDSR3	7.182	8.827	8.432	5.651	8.021	8.827
LDSR4	2.77	7.416	4.934	7.395	9.264	9.093
LDSR5	7.625	7.958	4.737	9.942	8.532	8.765

Table 3: Continue...

VV VH-1	Lodged direct seeded rice					
Sl. No	land preparation	Sowing	Germination	establishment stage	Tillering	Maximum tillering
LDSR6	6.533	9.472	7.464	7.619	9.643	6.903
LDSR7	6.569	6.92	6.954	6.19	8.708	10.608
LDSR8	7.093	8.29	4.327	6.955	11.102	7.494
LDSR9	5.869	7.498	7.137	4.486	7.404	8.789
LDSR10	6.301	9.539	6.139	5.677	8.354	11.069
Un-lodged direct seeded rice						
UDSR1	9.597	6.664	7.451	8.752	10.321	8.35
UDSR2	5.432	7.004	7.939	6.455	9.255	7.69
UDSR3	7.182	8.827	8.432	5.651	8.021	8.827
UDSR4	2.77	7.416	4.934	7.395	9.264	9.093
UDSR5	7.625	7.958	4.737	9.942	8.532	8.765
UDSR6	6.533	9.472	7.464	7.619	9.643	6.903
UDSR7	6.569	6.92	6.954	6.19	8.708	10.608
UDSR8	7.093	8.29	4.327	6.955	11.102	7.494
UDSR9	5.869	7.498	7.137	4.486	7.404	8.789
UDSR10	6.301	9.539	6.139	5.677	8.354	11.069

Table 3: Continue...

VV VH-1	Lodged direct seeded rice						
	Stem elongation	panicle initiation	Heading	Flowering	Dough stage	Maturity	Harvesting
LDSR1	9.09	5.626	4.242	6.255	4.528	3.254	4.268
LDSR2	6.473	5.565	4.779	6.834	5.206	3.412	3.54
LDSR3	7.829	4.923	5.84	7.71	4.902	6.868	4.791
LDSR4	4.658	4.91	5.489	4.848	3.545	7.588	5.543
LDSR5	3.481	4.16	4.991	3.987	5.399	3.884	6.614
LDSR6	5.56	4.953	2.834	3.83	2.576	4.412	4.269
LDSR7	9.545	4.431	3.475	5.727	5.12	6.698	3.484
LDSR8	6.954	5.045	1.975	4.377	6.838	4.259	4.207
LDSR9	6.219	4.558	4.183	4.791	3.502	5.112	5.036
LDSR10	8.851	4.983	3.832	3.279	4.201	4.158	4.941
Un-lodged direct seeded rice							
UDSR1	9.09	5.626	4.242	6.255	4.528	3.254	4.268
UDSR2	6.473	5.565	4.779	6.834	5.206	3.412	3.54
UDSR3	7.829	4.923	5.84	7.71	4.902	6.868	4.791
UDSR4	4.658	4.91	5.489	4.848	3.545	7.588	5.543
UDSR5	3.481	4.16	4.991	3.987	5.399	3.884	6.614
UDSR6	5.56	4.953	2.834	3.83	2.576	4.412	4.269
UDSR7	9.545	4.431	3.475	5.727	5.12	6.698	3.484
UDSR8	6.954	5.045	1.975	4.377	6.838	4.259	4.207
UDSR9	6.219	4.558	4.183	4.791	3.502	5.112	5.036
UDSR10	8.851	4.983	3.832	3.279	4.201	4.158	4.941

Table 4: Spectral back scattering of VH VV^{-1} band

VH VV^{-1}	Lodged direct seeded rice					
Sl. No	land preparation	Sowing	Germination	establishment stage	Tillering	Maximum tillering
LDSR1	-9.597	-6.664	-7.451	-8.752	-10.321	-8.35
LDSR2	-5.432	-7.004	-7.939	-6.455	-9.255	-7.69
LDSR3	-2.77	-7.416	-4.934	-7.395	-9.264	-9.093
LDSR4	-7.182	-8.827	-8.432	-5.651	-8.021	-8.827
LDSR5	-7.625	-7.958	-4.737	-9.942	-8.532	-8.765
LDSR6	-6.533	-9.472	-7.464	-7.619	-9.643	-6.903
LDSR7	-6.569	-6.92	-6.954	-6.19	-8.708	-10.608
LDSR8	-7.093	-8.29	-4.327	-6.955	-11.102	-7.494
LDSR9	-5.869	-7.498	-7.137	-4.486	-7.404	-8.789
LDSR10	-6.965	-8.187	-6.325	-6.545	-8.528	-10.563
Un-lodged direct seeded rice						
UDSR1	-9.597	-6.664	-7.451	-8.752	-10.321	-8.35
UDSR2	-5.432	-7.004	-7.939	-6.455	-9.255	-7.69
UDSR3	-2.77	-7.416	-4.934	-7.395	-9.264	-9.093
UDSR4	-7.182	-8.827	-8.432	-5.651	-8.021	-8.827
UDSR5	-7.625	-7.958	-4.737	-9.942	-8.532	-8.765
UDSR6	-6.533	-9.472	-7.464	-7.619	-9.643	-6.903
UDSR7	-6.569	-6.92	-6.954	-6.19	-8.708	-10.608
UDSR8	-7.093	-8.29	-4.327	-6.955	-11.102	-7.494
UDSR9	-5.869	-7.498	-7.137	-4.486	-7.404	-8.789
UDSR10	-6.965	-8.187	-6.325	-6.545	-8.528	-10.563

Table 4: Continue...

VH VV^{-1}	Lodged direct seeded rice						
Sl. No	Stem elongation	panicle initiation	Heading	Flowering	Dough stage	Maturity	Harvesting
LDSR1	-9.09	-5.626	-4.242	-6.255	-4.528	-3.254	-4.268
LDSR2	-6.473	-5.565	-4.779	-6.834	-5.206	-3.412	-3.54
LDSR3	-4.658	-4.91	-5.489	-4.848	-3.545	-7.588	-5.543
LDSR4	-7.829	-4.923	-5.84	-7.71	-4.902	-6.868	-4.791
LDSR5	-3.481	-4.16	-4.991	-3.987	-5.399	-3.884	-6.614
LDSR6	-5.56	-4.953	-2.834	-3.83	-2.576	-4.412	-4.269
LDSR7	-9.545	-4.431	-3.475	-5.727	-5.12	-6.698	-3.484
LDSR8	-6.954	-5.045	-1.975	-4.377	-6.838	-4.259	-4.207
LDSR9	-6.219	-4.558	-4.183	-4.791	-3.502	-5.112	-5.036
LDSR10	-9.718	-5.718	-3.976	-3.704	-3.782	-3.392	-4.769
Un-lodged direct seeded rice							
UDSR1	-9.09	-5.626	-4.242	-6.255	-4.528	-3.254	-4.268
UDSR2	-6.473	-5.565	-4.779	-6.834	-5.206	-3.412	-3.54
UDSR3	-4.658	-4.91	-5.489	-4.848	-3.545	-7.588	-5.543

Table 4: Continue...

VH VV^{-1}	Lodged direct seeded rice						
Sl. No.	Stem elongation	panicle initiation	Heading	Flowering	Dough stage	Maturity	Harvesting
UDSR4	-7.829	-4.923	-5.84	-7.71	-4.902	-6.868	-4.791
UDSR5	-3.481	-4.16	-4.991	-3.987	-5.399	-3.884	-6.614
UDSR6	-5.56	-4.953	-2.834	-3.83	-2.576	-4.412	-4.269
UDSR7	-9.545	-4.431	-3.475	-5.727	-5.12	-6.698	-3.484
UDSR8	-6.954	-5.045	-1.975	-4.377	-6.838	-4.259	-4.207
UDSR9	-6.219	-4.558	-4.183	-4.791	-3.502	-5.112	-5.036
UDSR10	-9.718	-5.718	-3.976	-3.704	-3.782	-3.392	-4.769

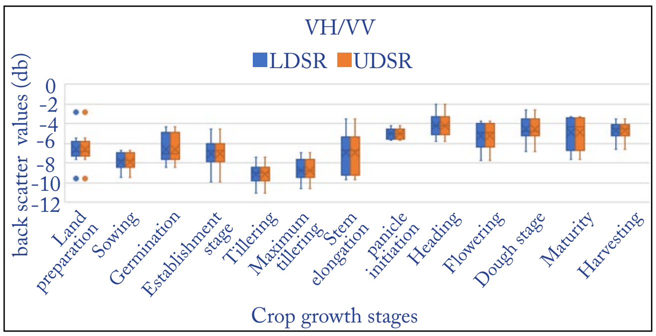

Figure 6: Graph showing spectral backscattering values

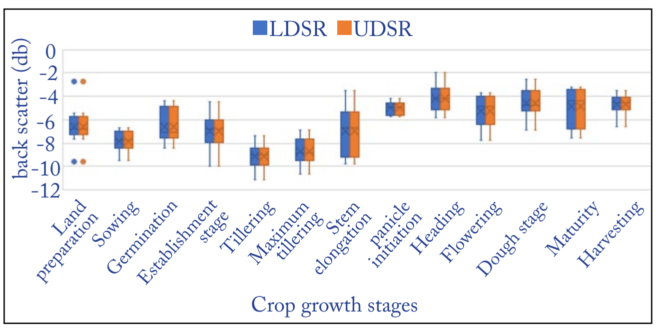

Figure 7: Graph showing spectral backscattering values

observed at both early and late stages.

The increase in spectral backscatter in lodged crops is attributed to the angle of incident radiation reaching the crop. For lodged crops, the angle with the ground may range from 0° to 45°, depending on the severity of lodging. As microwave radiation is highly sensitive to the surface characteristics of the target, the dielectric properties (soil type and moisture) and canopy water content play a key role (McNairn et al., 2009; Cable et al., 2014; Forkuor et al., 2014; Canisius et al., 2018). During the early stages of establishment, backscatter is primarily attributed to the soil background, while later, as the crop matures and covers the ground, the backscatter from the crop decreases, leading to lower values (Freeman and Durden, 1998; White et al., 2015).

3.4. Statical analysis of backscatter values

The spectral backscatter from the four polarizations was evaluated using a paired t-test with equal variances. The results indicated that the VV and VH polarizations showed significant differences at the 0.05% and 0.01% levels in discriminating lodged crops from unlodged crops. Similar studies have reported the ability of VV and VH bands to detect lodged crops in maize, wheat, and other crops (Yang et al., 2015; Chen et al., 2016; Zhao et al., 2017).

Table 5: Comparison of different polarizations using paired t test

Stage of the crop	Polarisation			
	VV	VH	VV VH^{-1}	VH VV^{-1}
Flowering	3.23519252479436**	2.55750754383321*	1.1243086	1.0022
Dough	3.69924213632094**	5.57239972572947**	-1.12336	1.152
Maturity	3.57509062297509**	6.3541070198651**	0.2011518	0.4583

T statistics **at (p=0.05) LOS is 2.101, T statistics value *at (p=0.01) LOS is 2.835

4. CONCLUSION

The study mainly focused on the discrimination of lodged rice crop from the unlodged crop at the flowering, dough, and maturity stages. The polarizations that were helpful in discriminating were VV and VH. The cross-polarization did not have any segregation effect on the lodging of the rice crop. The future line of work included mapping of the risk zones and the development of crop models that simulated climate data and its effects on crop lodging.

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