# PREFACE

Remote sensing technique is basically based on the accurate interpretation of interaction mechanism of electromagnetic waves with different features of the earth surface. The microwave scattering response of growth parameters of different crops and soil moisture depends on the frequencies, polarizations and incidence angles of the incident microwave, the phenological changes (leaf area index, biomass, crop height, crop water content etc.), dielectric constant of the scattering elements of crops at various growth stages and the soil surface parameters. The scattering coefficients are the key to understand and evaluate the target properties in microwave remote sensing. By measuring the crop canopy/soil surface scattering at multiple incidence angle in different microwave bands using full polarizations modes may be helpful to understand the affect of shape, size, orientation, density, and dielectric on the canopy scattering. The goal of our present work was to study bistatic radar response at multiple incidence angles, multiple frequencies and different polarizations for the estimation of crop growth parameters and soil moisture. In this thesis, we have performed an investigation, based on experimental measurements, to evaluate the potential of bistatic radar measurements for the estimation of crop growth parameters and soils moisture. The study of change in crop growth parameters at different crop growth stages is essential for monitoring and predicting the crop yield. However, the estimation of  crop growth parameters based on field measurements are often expensive, prone to enormous errors, and are unable to provide the real-time, spatially explicit information or forecasting of crops condition. The uses of remote sensing systems provide temporally, spatially and repetitively monitoring of Earth resources globally.

Up to now, theoretical and experimental research for land surfaces observations have been investigated by the ground based scatterometer system in the backscattering direction. The study of bistatic scattering mechanism of land surface observations is becoming a subject of growing interest due to its capability to acquire multidimensional information about the land use and land cover. However, till now, the theoretical studies of scattering mechanism of vegetation/soils in bistatic configuration are based on radiative transfer theory and electromagnetic scattering /emission model.

The estimation of crop growth parameters at different growth stages is important for monitoring the crop health conditions. The stress, if any, in the crop can be assessed immediately. The estimation of crop parameters may be also be used for growth monitoring and identification of crop type. To use radar for such purposes, direct models simulating the backscattering coefficients of a canopy have been widely developed. These models can be inverted to estimate the crop parameters and study the microwave response of varying crops/soil parameters. These models may be excellent tool for understanding the scattering mechanism and estimating the crop parameters.

Since, the bistatic scattering coefficients depends upon the several system parameters and crop growth parameters. Further, it involves very complex mathematical expressions for the computation of bistatic scattering coefficient. Therefore, the inversion of these models is computationally complex and tedious task for the estimation of crop growth parameters. Therefore, a robust and less complex technique is required for the estimation of crop parameters at various growth stages. To overcome the complex computational task, the machine learning techniques are being extensively used in scientific and engineering research. The machine learning techniques include artificial neural network (ANN), fuzzy logic (FL), genetic algorithm (GA) and support vector machine (SVM). The ANN, SVM and GA have been successfully applied in the field of agriculture for estimation and classification using remote sensing data. However, the fuzzy logic inference system is yet to be investigated in detail for the estimation of crop growth parameters using the remote sensing data. Therefore, in the present thesis, the potential of fuzzy inference system (FIS) was evaluated for the estimation of crop growth parameters at different microwave bands and polarizations. The performance of the developed FIS algorithm was also evaluated by calculating the root mean square error (RMSE) between the observed and estimated values of the crop growth parameters/soil moisture.

In the present thesis, bistatic measurements were carried out to study the microwave scattering response of growth parameters of some crops (rice, wheat and ladyfinger) at different growth stages and slightly rough soil surfaces at different soil moisture conditions using different configuration of sensor parameters. The computed bistatic specular scattering coefficients ($\sigma^0$) of the crops/soil were analysed with different crop growth parameters and soil moisture at different growth stages in the angular range of $10^0$-$60^0$ incidence angle, various polarizations and X-, C- and L-bands of the microwave. The correlation analysis between $\sigma^0$ and crop growth parameters was carried out to select the optimum angle of incidence, polarization and frequency of the bistatic scatterometer system for the estimation of crop growth parameters. The fuzzy inference system was used to estimate the crop parameters and soil moisture using bistatic scatterometer data.

The first Chapter describes the introductory background and brief review of some the research work carried out for monitoring the crops/vegetations and soil surfaces parameters by microwave remote sensing using different computational techniques.

The second Chapter describes an experimental procedure for the computation of bistatic scattering coefficients from different types of crops and the bare soil surfaces. It was also discussed about the measurements of different crop growth parameters and soil surface parameters. The major crop growth parameters such as fresh biomass (FBm), leaf area index (LAI), plant height (PH), and vegetation water content (VWC) were considered for the crops.

In the third Chapter, bistatic scatterometer measurements were performed on the rice crop-bed in the angular range of 20° to 60° for specular direction ($\phi = 0$) at X-, C- and L-bands for HH-, VV-, and HV-polarizations. The scattering contribution to bistatic specular scattering coefficients ($\sigma^0$) was analysed with the crop growth parameters at its different growth stages. The correlation analysis was done between $\sigma^0$ and crop growth parameters for different polarization at X-, C- and L-bands. The estimation of rice crop growth parameters using subtractive clustering based fuzzy inference system (S-FIS) was done at the highly correlated value.

In the fourth Chapter, multi-temporal and multi-angular bistatic scatterometer measurements were conducted on the specially prepared crop-bed of wheat at nine growth stages in the angular range of 20° to 60° for specular direction ($\phi = 0$) at multi-frequencies (X-, C-, and L-bands) for co-polarizations (HH- and VV-polarization). The grid partition based fuzzy inference system (G-FIS) using Gaussian membership function (Gauss MF) was evaluated to estimate the crop growth parameters at different growth stages.

In the fifth Chapter, the ground based bistatic scatterometer measurements of ladyfinger crop were conducted at its various growth stages in the specular direction with the azimuthal angle ($\phi = 0$) for the angular range of 20° to 60° incidence angle in steps of 10° for HH- and

VV- polarization at X-band. Artificial neural network was incorporated into fuzzy inference system to improve the estimation efficiency of the fuzzy inference system by tuning their parameters. The potential of subtractive clustering based adaptive neuro-fuzzy inference system (S-ANFIS) was applied for the estimation of crop growth parameters.

In the six Chapter, the potential of bistatic configuration of radar system were investigated for the estimation of soil moisture along specular direction($\phi = 0$). The bistatic radar data were collected by indigenously designed ground based scatterometer system for the 20°- 60° incidence angles at steps of 10° in the specular direction for HH -and VV- polarizations at L-band. The polarization behaviour of the microwave were analysed by using the co-polarization ratio($P = \frac{\sigma^{\circ}_{HH}}{\sigma^{\circ}_{VV}}$). The purpose of using $P$ is that it does not depend on the surface roughness parameters and its values depend upon the coherent components of the reflected microwave. Grid partitions based neuro-fuzzy inference system called G-ANFIS was used for estimation of soil moisture content. The different type of membership function (MF), such as Gaussian, Generalized bell and Triangular MF for partitioning of the data sets called grids, were investigated to estimate the soil moisture content.

Finally, the seventh Chapter describes the conclusions and future prospective of the research work of the present thesis.

Therefore, the findings of these studies for the estimation of crop growth parameters and soil moisture may be used to suggest suitable angle of incidence, polarization and different microwave bands for the future bistatic radar system to monitor the crops and soil fields effectively and to predict the sensor parameters for space borne and airborne more authentically through ground based observation using computational techniques. It will help in understanding of remote sensing application for various purposes, be it design of sensors, crop classification, crop-yield and soil moisture estimation or agricultural planning.