## LIST OF FIGURES

Figure 1.1 Total atmospheric transmission at different electromagnetic frequency
regions (Elachi and Van Zyl 2006)
Figure 1.2 Classification of microwave sensors (Ulaby et al. 2014)10
Figure 2.1 Geometry of the bistatic scatterometer system
Figure 2.2 Aluminum sheet used during the calibration of the system
Figure 2.3 Geometry of illuminated area by the beam on the target surface35
Figure 3.1 Surface roughness profile and auto correlation function for test soil surface
(RMS height ( $\sigma$ ) = 1.61cm and correlation length ( $l$ ) = 11.69 cm)45
Figure 3.2 Structure of BPANN used in the present study47
Figure 3.3 Structure of RBFANN model used in the present study
Figure 3.4 Structure of GRANN model used in the present study
Figure 3.5 Angular variation of scattering coefficients at various soil moisture
contents for (a) HH- and (b) VV- polarization at X-band53
Figure 3.6 Scatter plot between observed and estimated soil moisture for the training
of models at (a) HH- polarization and (b) VV- polarization with 1:1 lines59
Figure 3.7 Scatter plot between observed and estimated soil moisture for the
validation of models at (a) HH- polarization and (b) VV- polarization with 1:1 lines 60
Figure 3.8 Flow chart for the comparison of results
Figure 3.9 Taylor plot for the performance of different models during training at HH-
and VV- polarization61
Figure 3.10 Taylor plot for the performance of different models during validation at
HH- and VV- polarization
Figure 4.1 Growth stages of rice crop (a) vegetative stage, (b) reproductive stage and
(c) repining and maturing stage
Figure 4.2 Flow chart for the retrieval algorithm of rice crop variables71
Figure 4.3 Architecture of (a) FFBPANN-I model and (b) FFBPANN-II model for the
estimation of rice crop variables72
Figure 4.4 Angular variation of bistatic scattering coefficient at different growth
stages for HH-polarization74
Figure 4.5 Angular variation of bistatic scattering coefficient at different growth
stages for VV-polarization75
Figure 4.6 Performance of first FFBPANN models for the retrieval of rice crop
variables for (a) VWC (b) LAI (c) PH (d) SPAD value with different combination of
data sets79
Figure 5.1 Graphical representations of Gaussian function
Figure 5.2 (a-c) Temporal variation of VWC, LAI and plant height of kidney bean
crop fitted with Gaussian function
Figure 5.3 Architecture of ANN model used in the present study

Figure 5.4 Temporal variation of kidney bean crop variables for (a) VWC (b) LAI (c)
plant height and (d) SPAD value92
Figure 5.5 Photographs of various growth stages of kidney bean crop93
Figure 5.6 Angular variation of bistatic scattering coefficients for kidney bean crop at
different growth stages for HH- polarization
Figure 5.7 Angular variation of bistatic scattering coefficients for kidney bean crop at
different growth stages for VV-polarization
Figure 5.8 Flow chart of algorithm used for the estimation of kidney bean crop
variables
Figure 5.9 (a-d) Estimated crop variables and age of kidney bean by ANN model Vs
observed crop variables and age of kidney bean of the second crop bed98
Figure 6.1Temporal variations of wheat crop variables for (a) VWC (b) LAI (c) plant
height and (d) SPAD value104
Figure 6.2 Photographs of wheat crop at various growth stages105
Figure 6.3 Architecture of ANN model used in the present study106
Figure 6.4 Angular variation of bistatic scattering coefficient for wheat crop at
different growth stages for HH- polarization at X-band109
Figure 6.5 Angular variation of bistatic scattering coefficient for wheat crop at
different growth stages for VV- polarization at X-band109
Figure 6.6 Flow chart for the estimation procedure of the wheat crop variables111
Figure 6.7 (a-d) 1:1 axes plot between estimated and observed crop variables for (a)
VWC (b) LAI (c) PH and (d) SPAD value at HH- polarization113
Figure 6.8 (a-d) 1:1 axes plot between estimated and observed crop variables for (a)
VWC (b) LAI (c) PH and (d) SPAD value at VV- polarization115
Figure 7.1 Temporal variations of chickpea crop variables for (a) VWC (b) LAI (c)
plant height121
Figure 7.2 Photographs of wheat crop at various growth stages121
Figure 7.3 Angular variation of bistatic scattering coefficient for chickpea crop at
different growth stages for HH- polarization at X-band124
Figure 7.4 Angular variation of bistatic scattering coefficient for chickpea crop at
different growth stages for VV- polarization at X-band124
Figure 7.5 Flow chart for the estimation procedure of chickpea crop variables125
Figure 7.6 Architecture of developed BPANN model127
Figure 7.7 (a-c) 1:1 axes plot between estimated crop variables and observed crop
variables for (a) VWC (b) LAI (c) PH at HH- polarization128
Figure 7.8 (a-d) 1:1 axes plot between estimated crop variables and observed crop
variables for (a) VWC (b) LAI (c) PH at VV- polarization130