Satellite Based Crop Monitoring and Estimation System for Food Security Application in Bangladesh

Dr. Hafizur Rahman
Head, Agriculture Division
Bangladesh Space Research and Remote Sensing Organization (SPARRSO)
Email: hafiz1961@yahoo.com, Fax: 880-2-9122473

Presented in the Expert Meeting on Crop Monitoring for Improved Food Security, 17 February 2014, Vientiane, Lao PDR.

Summary

Food security is an increasingly important issue for Bangladesh under high demographic pressure, climatic disturbances due to global warming, climate change phenomenon etc. together with acute land resource constraint. Precise, appropriate and timely information on agricultural crops is a major concern under the prevailing circumstances. Satellite remote sensing technology offers an effective means for monitoring agricultural crops at large scale on a repetitive basis. Proper utilization of such technology is to be ensured to provide necessary information support to national food security program. SPARRSO being the national focal point of remote sensing technology has been regularly monitoring the major agricultural crop in the country for the last two decades and has been providing important information support to the government. The major activities include monitoring of growth and condition, discrimination of type and estimation of crop area particularly for Aman and Boro rice in the country. While, researches for monitoring of other important crops in the country are also underway at SPARRSO. Technical approach for remote sensing information retrieval through application and analysis of derivatives of space-based radiative measurements in the spatial, temporal, angular and spectral domain is quiet evident. SPARRSO recognizes four major concerns in developing an operational crop monitoring system in Bangladesh for effective information retrieval such as (i) Appropriate and timely satellite data, (ii) Effective RS algorithm based methodology, (iii) Mobile RS ground data collection platform along with a distributed observational ground network and (iv) Approach for partial automation of the associated operation and functionalities. SPARRSO has been working accordingly on the development of an integrated operational system supported with appropriate methodology for monitoring of agricultural crops in the country utilizing combined remote sensing (RS), Geographical Information System (GIS) and Global Positioning System (GPS) technologies. A coordinated technical approach involving the major ingredients as mentioned has been designed and is in the process of adoption to ensure better utilization of the technology in agricultural monitoring in the country. Exercises on model-based numerical operation are underway to device semi-automatic effective algorithms aiming towards more informational details. A knowledge-based artificial intelligence approach is under development for possible incorporation in the aforementioned operational monitoring system. Optimization of satellite data requirement considering the spatiotemporal dynamics of Earth's surface features is an on-going investigation process aiming towards developing an operational monitoring system at SPARRSO. Discrete ground based observation and RS field data collection and subsequent validation on stratified class categories distributed over the country has been recognized as an important input and has been integrated in satellite-based agricultural monitoring operation at SPARRSO. Eventually, SPARRSO is in the process of developing a Mobile RS platform supported with necessary RS instrumental facilities for ground-based observation and measurement of important biophysical parameters of crops conditioning the growth and yield. Finally, in order to strengthen the crop monitoring activities in the country, SPARRSO urges the development of broader scientific collaboration among the relevant field level organizations in the country constituting an effective ground-based observational network. Food and Agriculture Organization (FAO) has been playing an important role in addressing food security issue throughout the region since long time.

1. Introduction

Consequences of global warming, climate change, sea level rise phenomena have seriously affected the living world. Intensification of disasters like flood, cyclone, drought etc. in the recent years together with increased food demand by growing population imposed great challenges to the safety, security and livelihood of the people. Better monitoring mechanism of major agricultural crops is to be developed for national food security application. Necessary strategic planning is to be articulated to accomplish the objective. SPARRSO has been making continuous effort for the effective utilization of space and geoinformation technology to provide necessary crop information support towards food security application in the country.

Global climate change with intensification of disasters, shrinking of agricultural land due to rapidly growing population, disaster-induced crop damages etc. pose rising challenges of food security the world over. Proper management and possible remedial approaches for mitigation largely dependent on the availability of reliable and timely information on major crops and is a crucial issue in addressing the problem.

Development of remote sensing technology along with its repetitive and synoptic viewing capabilities has greatly improved our capability to monitor agricultural crops at large scale on a repetitive basis. Satellite remote sensing along with ground-based RS and other geospatial technologies offer immense potentialities and advantages in performing useful geospatial operation and functionalities addressing various geo-disciplinary problems. However, it should be kept in mind that such technologies are tools for many useful applications in various geo-disciplinary subject areas. Each of the RS application activities in different geo-disciplines has to be performed through development of proper operational procedure according to the necessities and circumstances.

Application of satellite remote sensing technology in agricultural crop monitoring is one of the major functions of Bangladesh Space Research and Remote Sensing Organization (SPARRSO). SPARRSO has been working with the objective to make contribution in monitoring major agricultural crops in the country. SPARRSO has been regularly performing the operation for agricultural crop particularly for Aman and Boro rice monitoring in the country for the last two decades and providing important information support to the government.

2.1 Interaction of Solar Radiation and Plant Growth

Solar radiation interacts with plant through reflection, absorption and transmission. Soil, water and vegetation possess individual spectral response characteristics. Figure 1 exhibits the spectral characteristics of a green vegetation. Radiation absorbed by plants is used for photosynthesis and also for maintaining temperature & transpiration. In the photosynthetic activity, chloroplasts absorb light energy. CO_2 and H_2O are combined with absorption of solar radiation to produce carbohydrate. Carbohydrate maintains the growth & development of a plant. Photosynthetic absorption over the life cycle is related to the growth & yield of crop. Presence of water in leaf is also an important criterion. Data interpretation provides information on the properties of vegetation & surface materials.

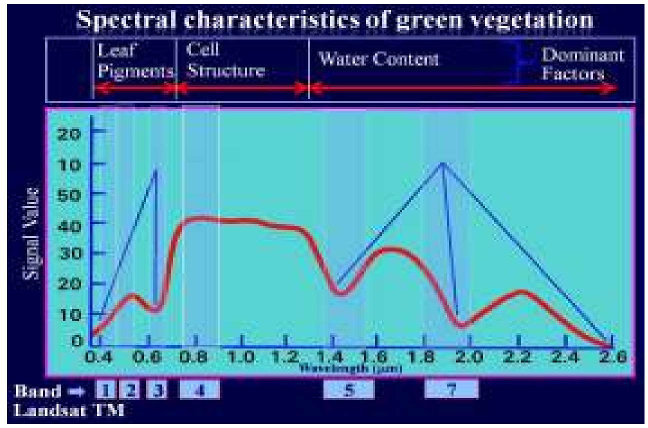

Figure 1. Spectral characteristics of green vegetation

Dynamic changes occur in the radiative transfer properties of vegetation during different growth phases. At early stage, increased chlorophyll in vegetation causes high photosynthesis producing more carbohydrate, enhancing growth. With the passage of time both leaf water & chlorophyll decrease as leaf dries up resulting in reduced photosynthesis.

The most important parameters under consideration are Leaf density, Ground coverage of crops, Chlorophyll concentration, Absorbed photosynthetically, active radiation (APAR), Incident solar radiation (PAR), Sunshine hour, Evapotranspiration rate, Daily cloud cover index, Rainfall, Temperature, Irrigation status, Radiometric crop responses.

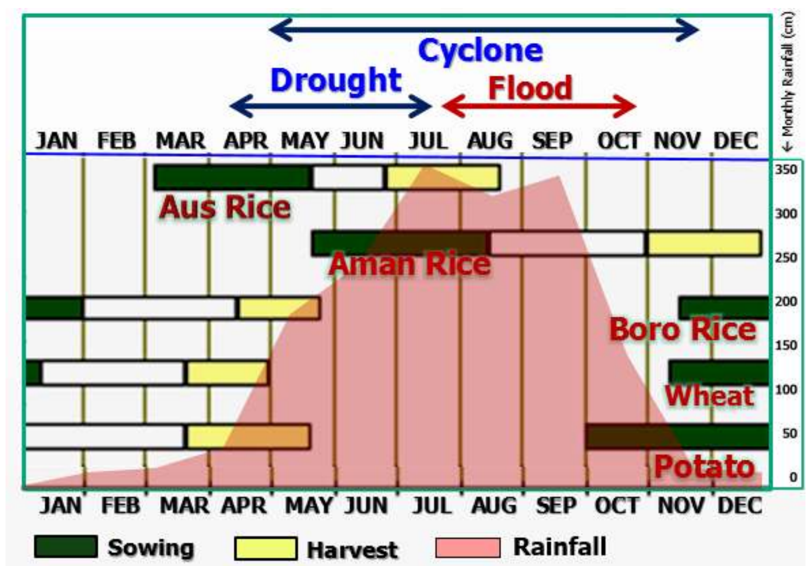

Figure 2. Calendar of major crops in Bangladesh with position of various disasters.

Seasonal cropping pattern largely influences the variation of spectral response pattern over seasonal crop areas which can be partly understood considering the crop calendar of a given geographical area. Figure 2 shows the calendar of major crops in Bangladesh with timing of major category of disaster events in the area.

Interaction of solar energy with the plant canopy takes place with absorption and scattering of incident solar radiation that exhibits distinct variation between different crops depending on the leaf architectural and optical properties. Multiple radiative processes are involved (Vogelmann and Bjorn, 1986; Kumar et al., 2001) in the determination of radiative responses at the sensor level. In the early stage, green vegetation has high chlorophyll content that causes high photosynthetic action in presence of leaf water and photosynthetic radiation producing more carbohydrate that enhances the plant growth. With the passage of time both leaf water and chlorophyll content decrease as leaf dries up resulting in reduced photosynthetic activity.

During the life cycle of an agricultural crop, the architectural and optical properties (*e.g.*, leaf area, vegetation height, vegetation cover, absorption, scattering of individual leaf elements *etc.*) change and follows a definite rhythm for each crop type (Sellers, 1985; Rahman, 2001. As a result, crops interact differently at each stage of its life cycle with the incident solar radiation and results in distinct variation in spectral characteristics. SPARRSO has been making effective use of these temporally evolving surface characteristics in relation to spectral variability to obtain valuable information on agricultural crops particularly of rice in Bangladesh (Choudhury et al.1999, , Rahman, 1999).

2. Application of Remote Sensing (RS) Technology

2.1 Basic Consideration

In satellite-based remote sensing, Earth's surface is illuminated by the Sun light and a portion of the incident Sun light is reflected or emitted by the surface. Satellite sensor receives the reflected or emitted sunlight coming from the surface after interaction with the surface features. RS technology makes utilization of the characteristics of the received signal through necessary radiative analysis. Basically, Earth surface features e.g. soil, water and vegetation have their individual spectral response characteristics depending on the condition, composition of the surface features and their dynamic changes over time. Satellite data interpretation provides information on the properties of the Earth's surface materials (Khlopenkov, wt al., 2004).

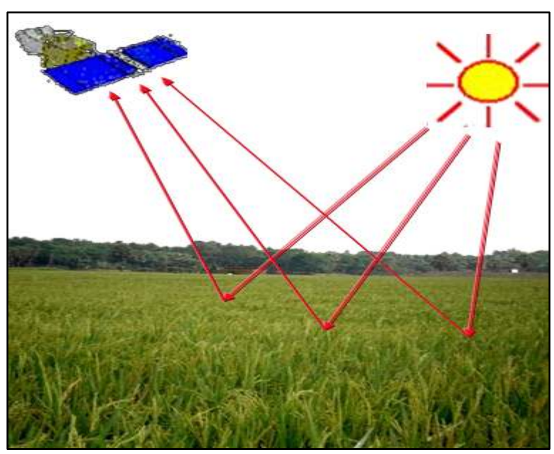

Figure 3. Geometrical configuration in a typical remote sensing system composed of illumination source (Sun), satellite, atmosphere and surface with different features. The geometrical parameters are Sun angle, viewing or observation angle and their relative azimuth angle.

Figure 3 represents the geometrical configuration of a typical remote sensing system. The system is composed of an illumination source (Sun), satellite, atmosphere and surface with different features. The intervening geometrical parameters are Sun angle, viewing or observation angle and their relative azimuth angle. Figure 3b represents the variation of remotely sensed field measured directional reflectance over a wheat crop in Sonargaon, Bangladesh at different growth stages Rahman et al., 1999). The figure shows the dynamics of surface radiative responses of wheat crop. Measurements have been carried out by SPARRSO as a part of its research activities on agricultural monitoring.

RS data generally correspond to measured radiation intensities expressed either in DN value or reflectance values as determined by the condition and composition of surface features and properties of the atmosphere at the time of data acquisition (Rahman, 1996; 1998). These data do not directly represent any physical parameter of the surface. Information is to be retrieved through appropriate numerical approach (Rahman et al., 1993a; 1993b) or by applying suitable classification procedure. In all cases of information retrieval, need for effective methodology with optimized data and resource requirement in crop monitoring aspect is well-recognized. Cost effectiveness and sustainability of the methodology is also important.

2.2 Optimizing Satellite Data Requirement at SPARRSO

SPARRSO utilizes a high resolution and medium resolution combination method for agricultural monitoring application. The high spatial resolution images provide the spatial details of crop distribution, while frequent (high temporal resolution) medium spatial resolution image provides the temporal dynamics of growing agricultural crops. Data fusion techniques are also applied to combine information from high and medium resolution digital images. In addition, a vegetation mask layer prepared from high resolution satellite data and updated at given time interval is also utilized to isolate a number of information layer e.g., forest and homestead vegetation areas etc.

Satellite data acquired by MODIS (Moderate Resolution Imaging Spectroradiometer) on board the satellite TERRA of USA are being utilized for the purpose. TERRA is a polar orbiting satellite with necessary spectral bands for vegetation monitoring. Time series daily data covering the life cycle of Aman and Boro rice are generally being used. Initial scrutiny through visual observation of time series data leads to relatively less cloud-affected images. Application of a digital cloud screening method identifies and removes the cloud in the images. In addition, high resolution satellite data as available e.g., Landsat TM, RADARSAT SAR etc. are also integrated.

3. Adopted Information Retrieval Approach at SPARRSO

3.1 Information Retrieval Using Numerical Approach

A two-step process is involved in retrieving information through a numerical approach (Rahman et al., 1993a; 1993b; Rahman, 2001) consisting of the following operations:

1) Establishing relationship between RS measurements & surface parameters through numeric model or function.

$$\rho = \rho_i(x, t, \lambda, \Theta)$$

λ - spectral dependency
Θ - geometry of observation-illumination
t - time
x - spatial coordinates

2) Mathematical inversion of the function against satellite data.

$$\frac{\partial \rho}{\partial x} \; or \; \frac{\partial \rho}{\partial t} \; or \; \frac{\partial \rho}{\partial \Theta} \; or \; \frac{\partial \rho}{\partial \lambda}$$

Variability in spatial, temporal, directional or spectral domain can be used to infer information.

3.2 Feature-based Characterization of Radiative Responses

Various factors govern the radiative response properties of a vegetation canopy system. The major factors include (i) Size and spatial extent of the crop fields, (ii) Spatial heterogeneity of surface features, (iii) Temporal dynamics of surface features, (iv) Spectral contrast between targeted class and other co-existing surface features and (v) Cloud obstacle etc. In such radiative transfer process, atmospheric constituents influences the radiative signal passing through the atmosphere in the double way trajectory from the Sun to surface and then surface to satellite path resulting in certain modification of the original signal (Tanre et al. 1983; Rahman, 1996). Proper data interpretation requires proper atmospheric correction of the satellite derived signal. Efficient tools are now available for such correction operation (Rahman and Dedieu, 1994).

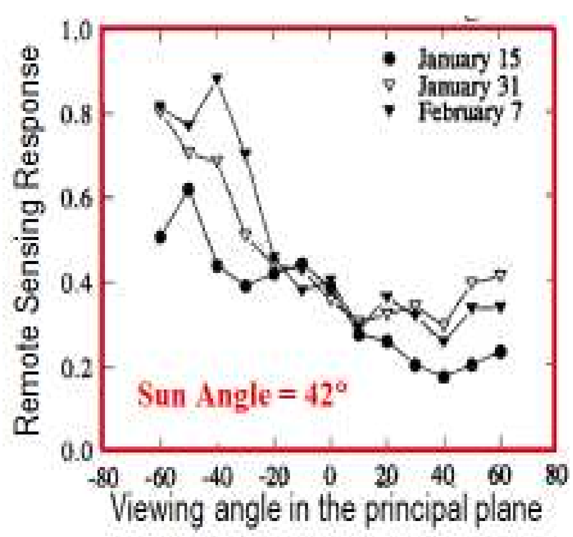

Figure 4a. Variation of remotely sensed field measured directional reflectance over a wheat crop in Sonargaon, Bangladesh at different growth stages showing dynamics of surface radiative responses of wheat crop. Measurements have been carried out by SPARRSO as a part of its research activities on agricultural monitoring.

SPARRSO makes utilization of satellite remote sensing-based radiation characterization through spatiotemporal modeling and analysis of spectral properties of crop temporal dynamics in the context of Bangladesh.

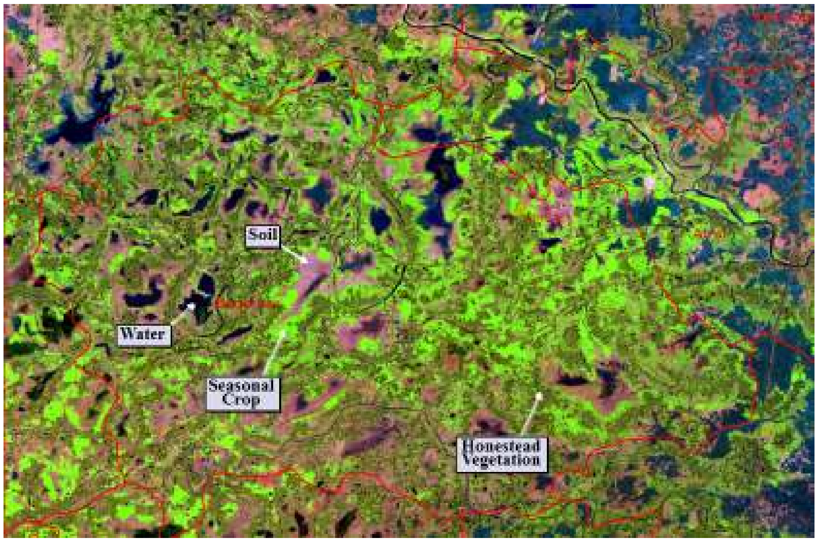

Figure 4b. Feature identification through spectral characterization of Landsat TM colour composite of January 21 2010 Bands 5,4,3 (RGB) (source: SPARRSO).

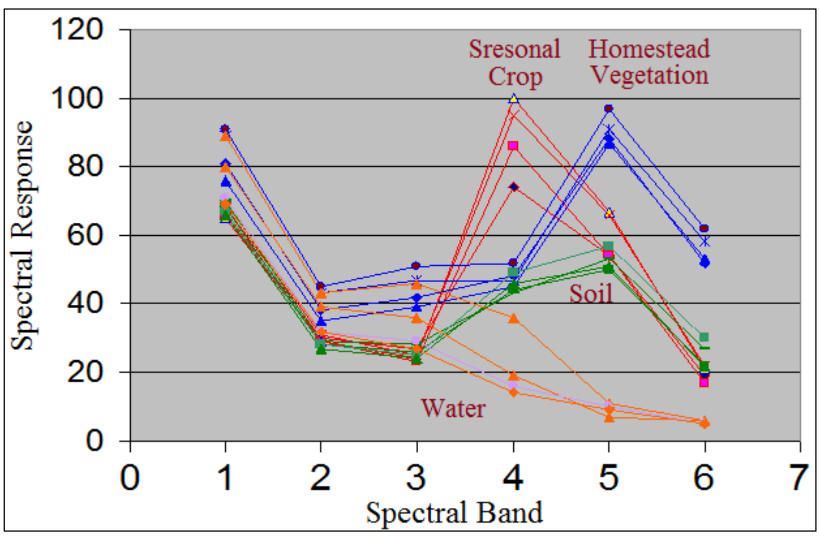

Figure 4c. Basis for spectral relational approach discriminating feature types.

4. Towards Operationalization of Crop Monitoring at SARRSO

4.1 Crop Type Discrimination

Crop type discrimination process consists of analysis of temporal and spatial variability of vegetation spectral radiative responses. In such process, amplitude and temporal variation of crop spectral response are evaluated. The logic behind is different crops provide different pattern and time phasing of its spectral responses (Rahman et al., 1999). Eventually, these variations are used in retrieving information on surface cover utilizing either a classification protocol or a model-based technic employing numerical modelling approach through optimization procedure for possible solution (Weiss et al., 2000; Rahman et al., 1993a; 1993b) or through index-based operation (Seller 1985; 1987; Gobron et al., 2000). In parallel fruitful application of crop calendar in relation to growth rhythm of vegetation is to be made as a step for crop type discrimination.

Figure 5 (a) shows the measured variation of height of rice plant during the developing time phase, while figure 5 (b) shows the temporal variation of spectral response of wheat crop as a function of day after plantation over the crop life time for varying viewing angle. The study has been performed under a research work conducted by the Agriculture division of SPARRSO.

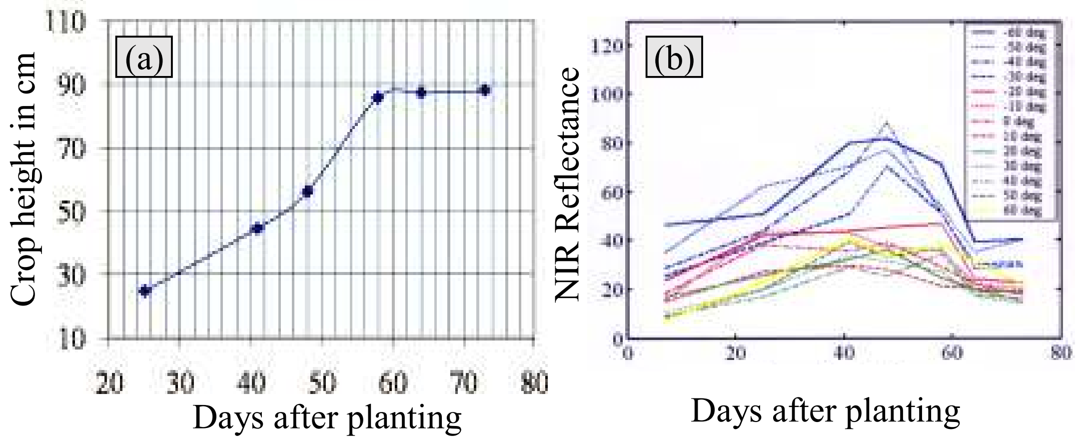

Figure 5 (a) Measured variation of height of rice plant during the developing time phase, (b) Temporal variation of spectral response of wheat crop as a function of day after plantation over the crop life time for varying viewing angle. The study has been performed under a research work conducted by the Agriculture division of SPARRSO.

4.2 Spectral Profiling and Biophysical Characterization

This is an important part of the whole crop assessment activity. This particular operation involves selection of profile points at features of interest over satellite image based on coordinate as given by GPS-supported geographical positioning. The subsequent operation includes extraction of spectral profiles from multi-date images. GPS-based positioning and field data collection at selected profile points. Relevant ground truth equipment are involved for location-based measurements of biophysical parameters.

Figure 6 represents the ground-based profiling at selected points covering the country and measurement of biophysical parameters using various RS ground equipment along selected road network points guided by GPS. Operation has been performed by SPARRSO as a part of implementation of agricultural monitoring program of SPARRSO.

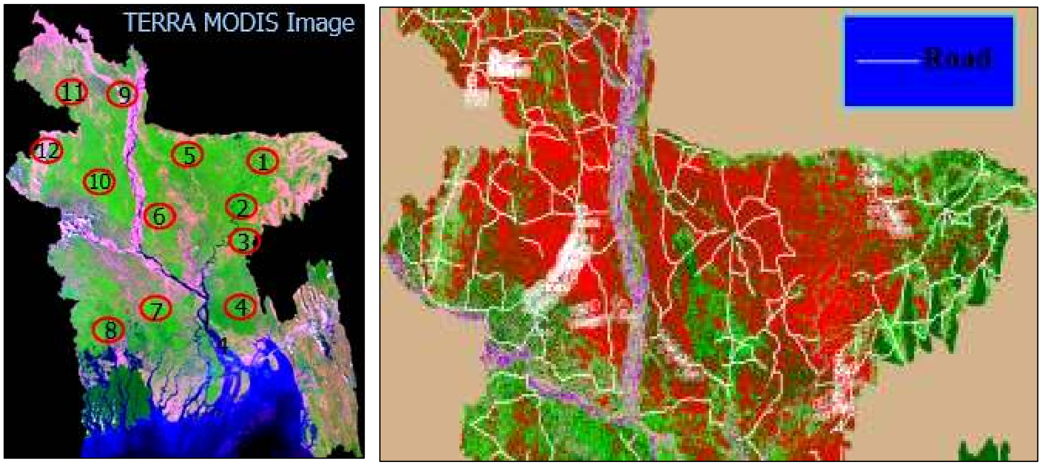

Figure 6. Ground based profiling at selected points covering the country and measurement of biophysical parameters using various RS ground equipment along selected road network points guided by GPS. Operation has been performed by SPARRSO as a part of implementation of agricultural monitoring program of SPARRSO.

5. Crop Monitoring, Analysis and Estimation System (CEAMONS) of SPARRSO

The adopted methodological approach of SPARRSO consists of digital radiometric analysis of temporal and spatial variability of vegetation responses. Analysis depicts that satellite-derived radiative measurements performed at different wavelengths of radiation exhibit systematic variation between different surface types depending on the condition, properties and composition of the surface features.

Figure 7 exhibits the algorithmic steps for crop monitoring as designed by SARRSO using satellite remote sensing integrated with GIS and geospatial technology supported with ground-based RS biophysical measurement and observation platform. The whole system is designed by SPARRSO and is named as Crop Monitoring, Analysis and Estimation System (CEAMONS). Implementation of the whole system is under development with subsequent step-wise validation and testing operation.

Dynamic temporal behaviour of agricultural crops as demonstrated through amplitude and pattern of satellite-based temporal radiative responses for a given crop is responsive to the type and condition of crop (Rahman et al., 1999). Individual characteristics of different vegetation crops and timing of cultivation provide unique pattern and time phasing in the observed data. Such variations are generally used in retrieving information on surface cover particularly regarding agricultural crops.

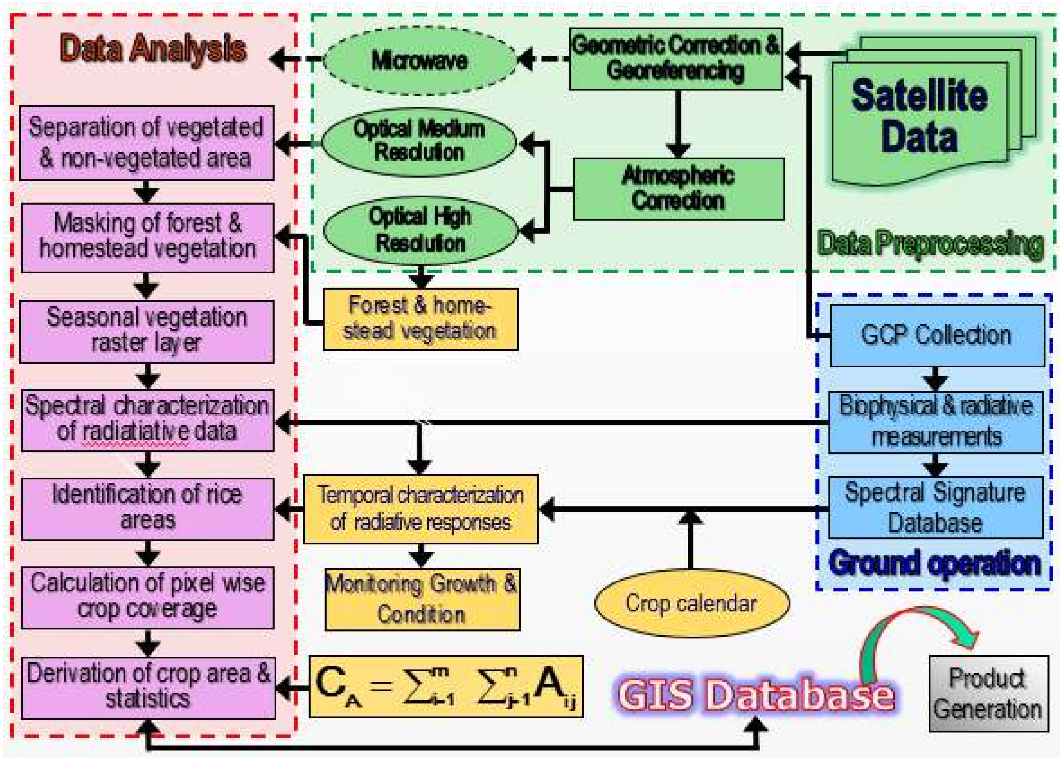

Figure 7. Algorithmic steps for crop monitoring as designed by SARRSO using satellite remote sensing integrated with GIS and geospatial technology supported with ground-based RS biophysical measurement and observation operation. Implementation of the whole system is under way with subsequent step-wise validation and testing operation.

A knowledge-based digital technique has been employed in supplementing the information retrieval process. A mathematical time derivative of the radiative responses ($\partial\rho/\partial t$) provides an estimation of the growth of the crop. Specially designed GPS (Ground Positioning System) based sample field surveys are generally being carried out over stratified selected locations fairly distributed over the country. The purpose of field survey is to support the analysis processes and to verify certain data interpretations. The rice areas are calculated by pixel-wise analysis of radiative transfer values in the spatiotemporal domain – a methodology devised by SPARRSO.

5.1 Implementing CEAMONS Crop Monitoring Algorithm at SARRSO

RS-GIS Agricultural Decision Support System at SPARRSO is configured with (i) Comprehensive geospatial database (satellite-borne and others), (ii) RS methodological framework with appropriate algorithm for monitoring of major agricultural crops, (iii) Protocol for time series geospatial data analysis, (iv) Database of spectral signature of surface features and (v) Measurements of temporally evolving biophysical crop parameters.

The whole operational system has been configured in three mutually interlinked functional blocks for monitoring and estimation of major agricultural crops by SPARRSO. The schematic diagram of the three functional blocks are as given below (Rahman, 2011). Figure 8a shows functional block 1 corresponding to cloud-free satellite data selection, preprocessing and generation of primary information layers for crop monitoring using satellite remote sensing by SARRSO.

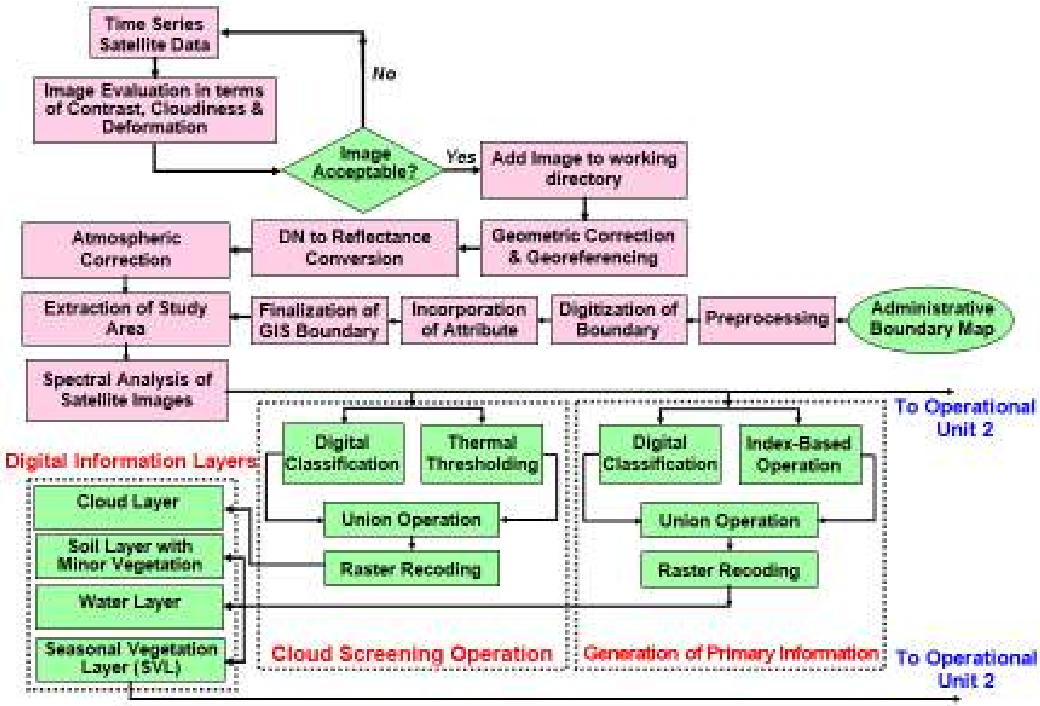

Figure 8a. Functional block 1 corresponding to cloud-free satellite data selection, preprocessing and generation of primary information layers for crop monitoring using satellite remote sensing by SARRSO.

Figure 8b shows functional block 2 comprising of GPS-based field investigation and satellite image-based numerical calculation and analysis operation. While figure 8c demonstrates function block 3 of the crop monitoring algorithm of SPARRSO using satellite remote sensing by SARRSO.

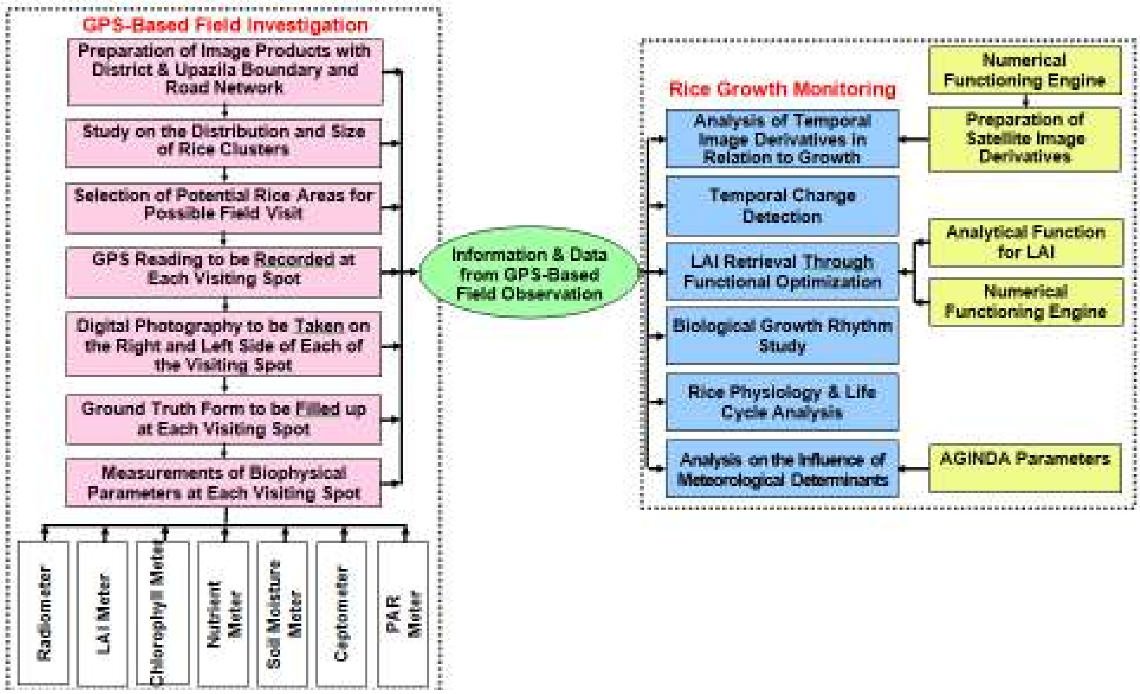

Figure 8b. Functional block 2 comprising of GPS-based field investigation and satellite image-based numerical calculation and analysis operation (SPARRSO).

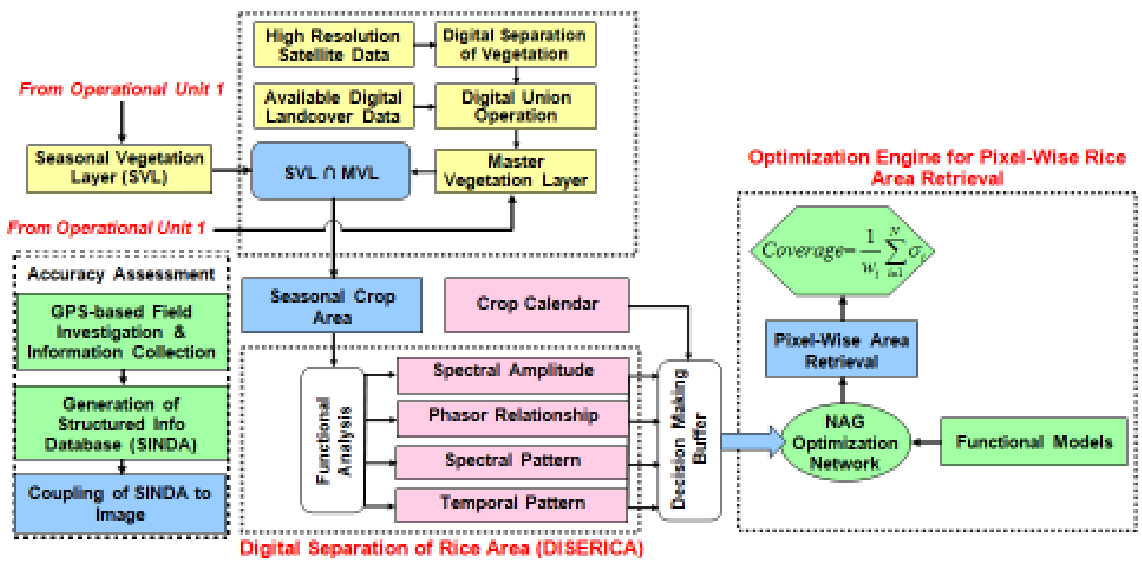

Figure 8c. Function block 3 of the crop monitoring algorithm of SPARRSO using satellite remote sensing by SARRSO.

In order to strengthen the crop monitoring activities at SPARRSO, the organization is in the process of development of broader scientific collaboration with the other relevant field level organizations in the country. Exercises on model-based numerical operation are underway to device semi-automatic effective algorithms aiming towards more informational details.

Discrete ground based observation on stratified class categories is an important input in agricultural monitoring using remote sensing technology. SPARRSO is in the process of developing significant instrumental facilities for ground-based observation and measurement of important biophysical parameters of crops conditioning the growth and yield. The attached diagrams demonstrate step-wise procedures on which SPARRSO has been presently working with an effort to develop its operational crop monitoring system with semi-automation scheme.

6. Possible Collaborative Approach

SPARRSO, Bangladesh Bureau of Statistics (BBS) and Department of Agriculture Extension (DAE) – the three government organizations of Bangladesh working together for effective crop monitoring in the country through combined application of RS-GIS and conventional field-based technology. Availability of satellite data of appropriate time frame, spatial coverage and technical specification appear to be a major concern in effective utilization of RS technology for crop monitoring. SPARRSO has been working on an optimizing RS data utilization protocol for operational rice crop monitoring in Bangladesh.

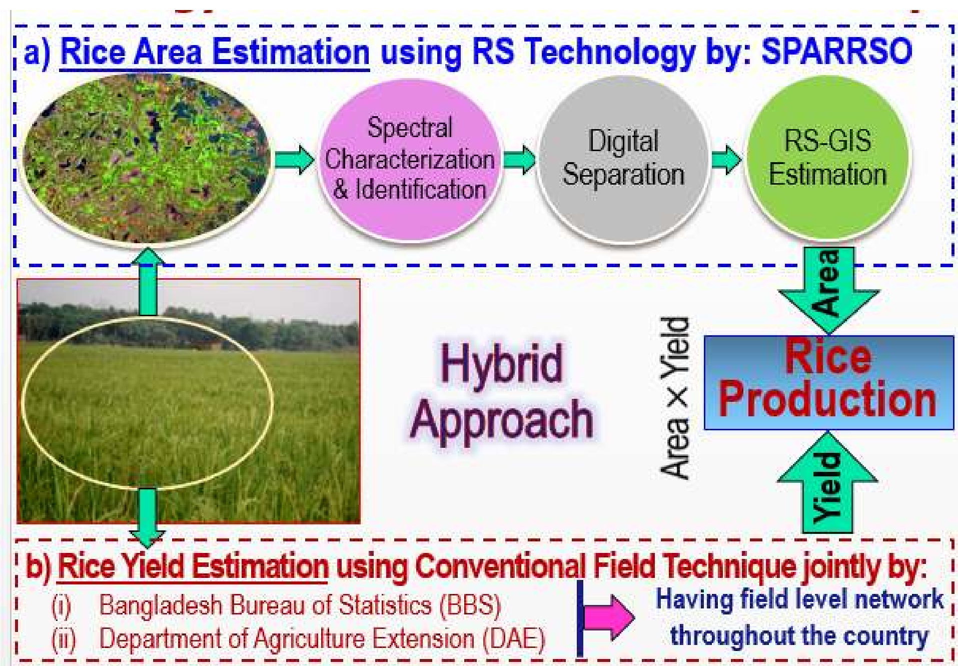

Figure 9. Strategy towards estimation of rice crop area applying remote sensing technology integrated with conventional field-based technique (source: SPARRSO). System is under design for possible consideration..

A numerical approach has been adopted to address mixed pixel problems in satellite image analysis and it seems to be effective. Figure 9 shows strategy towards estimation of rice crop area applying remote sensing technology integrated with conventional field-based technique (source: SPARRSO). The system is under development.

7. Conclusions

Space based RS along with geospatial technology appears to be an effective tool to extract information regarding condition and growth of agricultural crops. Proper utilization of the powerful technology of satellite remote sensing has to be ensured and its application area is to be multiplied under proper methodological framework in various geo-disciplinary subject areas through development of proper algorithm and methodology. Possible utilization of the RS and geospatial technology with incorporation of necessary field based technology should be considered to obtain better and optimum output. It should be kept in mind that RS technology is a tool or a series of tools for accomplishing various geospatial functioning and operations. However, to accomplish a desired operation and to produce useful outputs or to achieve a desired goal, necessary operational framework has to be developed where RS technology along with other supporting tools has to be effectively configured with properly designed functional methodologies and algorithms.

SPARRSO has been working for better utilization of such RS and geospatial technology in the country and has already made significant progress. Availability of satellite data of appropriate characteristics is a prime concern and has to be ensured. Necessary RS ground truth equipment enhances the crop monitoring approach. Inter-organizational collaborative programs involving modern remote sensing and conventional field based approach have to be developed at national level to better utilize the resources achieving better precision on the retrieved information. SPARRSO has been working for proper and efficient utilization of the available resources and technology to better serve the country. Implementation activities are underway.

Food and Agricultural Organization (FAO) has been playing a very important role to address the issues. FAO should maintain and provide increased support to enhance the utilization of the RS and geospatial technology throughout the region for better food security under the threat of global warming and climate change phenomena.

Acknowledgement

The author is thankful to Food and Agricultural Organization (FAO) for arranging the important workshop and for providing necessary support to participate in the workshop.

References

1) Choudhury, A.M., Quadir, D.A., Nessa, M., Islam, A.Z.M. and Hafizur Rahman, 1999, Application of remote sensing and GIS technology for large-scale winter rice assessment in Bangladesh. Journal of Remote Sensing and Environment, Vol. 3, 1-20.

2) Galvao, L.S., Ponzoni, F.J., Epiphanio, J.C.N., Rudorff, B.F.T. and A.R. Formaggio, 2004, Sun and view angle effects on NDVI determination of land cover types in the Brazilian Amazon region with hyperspectral data. International Journal of Remote Sensing, 25, 1861-1879.

3) Hafizur Rahman, 1996, Atmospheric optical depth and water vapour effects on the angular characteristics of surface reflectance on NOAA AVHRR channel 1 and channel 2. International Journal of Remote Sensing, 17, 2,981-2,999.

4) Hafizur Rahman, 1998, Effects of Atmospheric Optical Depth on the Data Acquired in the Visible and Near-Infrared Bands of Landsat TM. Geocarto International, Hong Kong, Vol. 13, No. 2, 5-10.

5) Hafizur Rahman, 2001, Influence of Atmospheric Correction on the Estimation of Biophysical Parameters of Crop Canopy Using Satellite Remote Sensing. International Journal of Remote Sensing (Taylor and Francis Publishers, UK), Vol. 22, No. 7, 1245-1268.

6) Hafizur Rahman, 2011, Strategies for a satellite-based integrated agricultural crop monitoring system at SPARRSO. Proceedings of the national seminar on Space technology application for monitoring Earth resources, disasters and climate change impacts for ensuring human security and sustainable development, SPARRSO, 28-29 June, 2011, 44-52.

7) Hafizur Rahman and G. Dedieu, 1994, SMAC: A simplified method for the atmospheric correction of satellite measurements in the solar spectrum. International Journal Remote Sensing, Vol. 15, pp 123-143.

8) Hafizur Rahman, Pinty, B. and M.M. Verstraete. 1993a. Coupled surface-atmosphere reflectance (CSAR) model 1. Model description and inversion on synthetic data. Journal of Geophysical Research, Vol. 98, No. D11, pp 20,779-20,789.

9) Hafizur Rahman, Pinty, B. and M.M. Verstraete, 1993b, Coupled surface-atmosphere reflectance (CSAR) model 2. Semiempirical surface model usable with NOAA Advanced Very High Resolution Radiometer Data. Journal of Geophysical Research, 98, 20,791-20,801.

10) Hafizur Rahman, Quadir, D.A., Islam, A.Z.Md. and Sukumar Dutta, 1999, Viewing Angle Effect on the Remote Sensing Monitoring of Wheat and Rice Crops. Geocarto International (a Multi-disciplinary Journal of Remote Sensing and GIS), Hong Kong, Vol. 14, No. 1, 75-79.

11) Khlopenkov, K., Trishchenko and Y. Luo, 2004, Analysis of BRDF and albedo properties of pure and mixed surface types from Terra MISR using Landsat high-resolution land cover and angular unmixing technique. Fourteenth ARM Science Team Meeting Proceedings, Albuquerque, New Mexico, March 22-26, 2004.

12) Kumar, L., Schmidt, K.S., Dury, S., Skidmore, A.K., 2001, Imaging spectrometry and vegetation science. In F. van de Meer. and S.M. de Jong (Eds). Imaging Spectrometry (Kluwer Academic Press: Dordrecht), pp 111-155.

13) Martonchik, J., D., Diner, D., Pinty, B., Verstraete, M., M., Myneni, R., Knyazikhin, Y., and H. Godron, 1998, Determination of land and ocean reflective, and biophysical properties using multiangular imaging. IEEE Transaction on Geoscience and Remote Sensing, 36, 1,266-1,281.

14) Sajidur Rahman, Hafizur Rahman and Mumnunul Keramat, 2007, Study on the Seasonal Changes of Land Cover and Their Impacts on Surface Albedo in the North-Western Part of Bangladesh using Remote Sensing. International Journal of Remote Sensing (Taylor and Francis Publishers, UK), Vol. 28, Issue 5, 1001-1022.

15) Sarker, M.H. and Hafizur Rahman, 2007, Crop Growth Monitoring over Bangladesh using NOAA AVHRR Based Normalized Difference Vegetation Index (NDVI) Time Series Data. Journal of Remote Sensing and Environment, Vol 4, 7-28.

16) Sellers, P.J., 1985, Canopy reflectance, photosynthesis and transpiration. International Journal of Remote Sensing, 6, 1335-1372.

17) Sellers, P.,J., 1987, Canopy reflectance, photosynthesis, and transpiration II: The role of biophysics in the linearity of their interdependence. Remote Sensing Environment, 21, 143-183.

18) Tanré, D., M. Herman, and P. Y. Deschamps, 1983, Influence of the atmosphere on space measurements of directional properties. Applied Optics, 22, 733-741.Tucker, C.J. and P., J., Sellers, 1986, Satellite remote sensing of primary production. International Journal of Remote Sensing, 7, 1,395-1,416.

19) Vogelmann T.C. and Björn L.O., 1986, Plants as light traps, Physiol. Plantarum, 68:704-708.

20) Weiss, M., Baret, F., Myneni, R.B., Pragnere, A., Knyazikhin, Y., 2000, Investigation of a model inversion technique to estimate canopy biophysical variables from spectral and directional reflectance data. *Agronomie*, 20, 3–22.