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CROP MONITORING FOR IMPROVED FOOD SECURITY

Proceedings of the Expert Meeting

Vientiane, Lao People's Democratic Republic

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Crop monitoring for improved food security

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Foreword

The Food and Agriculture Organization of the United Nations (FAO) is mandated to provide technical assistance to countries to build their capacities to produce timely and reliable information at the country level for mitigating food insecurity risks and for planning related government interventions and programmes.

Estimates and forecasts of crop area and yield are of critical importance to policy makers for the planning of agricultural production and monitoring of food supply. The possible links between poverty and crop yields, which depend upon a variety of factors such as cultivation practices, availability of irrigation, access to resources to buy agricultural inputs for adoption of new technology, cannot be fully understood without reliable estimates of crop area and yields. In the absence of reliable information on crop productivity the reasons behind food insecurity of agricultural households cannot be precisely identified.

The research agenda of the Global Strategy to Improve Agricultural and Rural Statistics foresees the potential of alternative methods and opportunities such as advances in satellite-based technology, for improving crop estimation and monitoring. Many institutions in Asia and Pacific region are using remotely sensed data in conjunction with conventional statistical methodologies to estimate the crop area and to forecast yield. These methods have seen a diverse degree of success, depending upon the nature of agriculture and/or access to advanced satellite imagery. A comparative study of these methods is needed to formulate technical recommendations to the countries who want to adopt these new technologies as an integral part of their statistical programme.

The Expert Meeting on Crop Monitoring for Improved Food Security, organized as a side event of the 25th Session of the Asia and Pacific Commission on Agricultural Statistics (APCAS) held in Vientiane, Lao PDR, provided an occasion for over 50 experts from Asia and other regions to deliberate on best practices and methodological issues, and to identify challenges for future research work. The partnership with the Asian Development Bank (ADB) in the organization of the meeting enriched the technical content of the meeting.

This publication summarizes the outcomes of the deliberations in the meeting and puts together a series of technical papers presented in the meeting and some reference papers. We hope this document will be a useful reference document for those interested in improving the current agricultural statistics using modern technologies. FAO remains committed to working with all stakeholders in its endeavour to make a desired contribution towards the sustainable development of agricultural and rural statistics systems of the countries in this region and elsewhere.

Hiroyuki Konuma
Assistant Director-General and Regional Representative
FAO Regional Office for Asia and the Pacific

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The meeting was organized at the initiative of the FAO Regional office for Asia and the Pacific with technical and financial contribution from the Asian Development Bank (ADB), and logistic support from the Government of Lao PDR and the Sustainable Agriculture and Environment Development Association (SAEDA).

Technical contributions to the meetings and this publication from a number of leading research institutions in the region and experts from selected countries are acknowledged.

The meeting was organized under the technical leadership and guidance of Mukesh K. Srivastava, Senior Statistician, FAO and Dalisay S. Maligalig, Principal Statistician, ADB. Seevalingum Ramasawmy, Statistician from FAO, handled the administrative arrangements and facilitated the meeting. Dalip Singh, Statistician from Regional Office for Global Strategy to Improve Agricultural and Rural Statistics, drafted the proceedings of technical sessions. Yohei Kunikane, Technical Officer from FAO, organized the event, followed up with the authors of technical papers and coordinated this publication.

The language editing of this publication was undertaken by Janice Naewboonnien. Valuable inputs and comments received from authors at different stages of preparation of this publication are appreciated.

Abbreviations and acronyms

ADB	Asian Development Bank
AFSIS	ASEAN Food Security Information System
ALIS	Agricultural Land Information System
ALOS	Advanced Land Observing Satellite
AMAF	ASEAN Ministers on Agriculture and Forestry
AMIS	Agricultural Market Information System
APAR	Absorbed Photosynthetically Active Radiation
APCAS	Asia and Pacific Commission on Agricultural Statistics
APRSAF	Asia-Pacific Regional Space Agency Forum
ASAR	Advanced Synthetic Aperture Radar
ASEAN	Association of Southeast Asian Nations
ASF	Area Sampling Frame
ASIP	Agricultural Survey Improvement Programme
AVHRR	Advanced Very High Resolution Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
BAS	Bureau of Agricultural Statistics
BBS	Bangladesh Bureau of Statistics
BMT	Before Mature Stage
BPPT	Badan Pengkajian dan Penerapan Teknologi (Agency for the Assessment and Application of Technology, Indonesia)
BSIT	Bureau of Statistics and Information Technology, Iran
CAPE	Crop Acreage and Production Estimation
CAS	Chinese Academy of Sciences
CBS	Central Bureau of Statistics
CCD	Charge-Coupled Device
CCE	Crop Cutting Experiments
CEAMONS	Crop Estimation, Analysis and Monitoring System
CGSM	Crop Growth Simulation Model
CO	Central Office
CPTP	Crop Planting and Type Proportion
CPU	Central Processing Unit
CSV	Comma-Separated Values
CV	Coefficient of Variation
DAC	Department of Agriculture and Cooperation
DAE	Department of Agriculture Extension, Bangladesh
DAG	Delete-a-Group
DEM	Digital Elevation Model
DN	Digital Number
DNPP	Direktur Nasional Penelitian dan Pengembangan (National Directorate for Policy and Planning)
DSLR	Digital Single-Lens Reflex
DSM	Digital Surface Model
ENVISAT	Environmental Satellite
EO	Earth Observation
ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
ESU	Elementary Sampling Unit
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAORAP	FAO Regional Office for Asia and the Pacific

FASAL	Forecasting Agricultural output using Space, Agro-meteorology and Land-based observations
FBD	Fine Beam Double Polarisation
FBS	Fine Beam Single Polarisation
FY	Fiscal Year
GEO	Group on Earth Observations
GEOGLAM	GEO Global Agricultural Monitoring initiative
GIS	Geographic Information System
GISTDA	Geo-Informatics and Space Technology Development Agency of Thailand
GPS	Global Positioning System
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communications
GT	Ground Truth
GTS	Ground Truth Survey
HDUAPS	Harmonization and Dissemination of Unified Agricultural Production Statistics
HQ	Headquarters
HWSD	Harmonized World Soil Database
ICT	Information and Communication Technology
INAHOR	International Asian Harvest Monitoring System for Rice
INSAT	Indian National Satellite System
IRRI	International Rice Research Institute
IRS	Indian Remote Sensing Satellite
ISRO	Indian Space Research Organization
IT	Information Technology
ITC	International Institute for Aerospace Survey and Earth Observation, Netherlands
JASMIN	JAxa's Satellite based Monitoring Network system
JAXA	Japan Aerospace Exploration Agency
JICA	Japan International Cooperation Agency
KBDI	Keetch-Byram Drought Index
LAI	Leaf Area Index
LISS	Linear Imaging Self-scanning Sensor
LSF	List Sampling Frame
MAFF	Ministry of Agriculture, Forestry, and Fisheries
MDG	Millennium Development Goals
MFS	Multiple Frame Survey
MOAFC	Ministry of Agriculture, Food Security and Co-operatives
MODIS	Moderate Resolution Imaging Spectroradiometer
MOJA	Ministry of Jihad-e-Agriculture
MRS	Medium Resolution ScanSAR
MSE	Mean Squared Error
MXL	Maximum Likelihood
NADAMS	National Agricultural Drought Assessment and Monitoring System
NAIC	National Agriculture Information Center
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NBS	National Bureau of Statistics
NCFC	National Crop Forecast Centre
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIAPP	National Institute of Agricultural Planning and Projection
NIR	Near-infrared

NOAA	National Oceanic and Atmospheric Administration, United States Department of Commerce
NRL	Land and Water Division, FAO
NRSC	National Remote Sensing Centre
NSO	National Statistical Organization
OC	Operation Center
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PC	Personal Computer
PCA	Principal Component Analysis
PDA	Personal Digital Assistant
PDR	People's Democratic Republic
PPS	Probabilities Proportional to Size
PSU	Primary Sampling Unit
RESTEC	Remote Sensing Technology Center of Japan
RF	Raising Factors
RGB	Red, Green, Blue
RIICE	Remote Sensing-based Information and Insurance for Crops in Emerging Economies
RISAT	Radar Imaging Satellite
RMSE	Root Mean Square Error
R-PATA	Regional Policy and Advisory Technical Assistance
RS	Remote Sensing
SAC	Space Applications Centre
SAEDA	Sustainable Agriculture & Environment Development Association
SAFE	Space Application for Environment
SAR	Synthetic Aperture Radar
SARI	Satellite Assessment of Rice in Indonesia
SASI	Shortwave Angle Slope Index
SCI	Statistical Centre of Iran
SE	Standard Error
SEBAL	Surface Energy Balance Algorithm for Land
SIAP	Statistical Institution for Asia and the Pacific
SID	Statistics and Informatics Division
SLC	Single Look Complex
SMS	Short Message Service
SPARRSO	Bangladesh Space Research and Remote Sensing Organization
SPARS	Strategic Plans for Agricultural and Rural Statistics
SRS	Simple Random Sampling
SRTM	Shuttle Radar Topography Mission
SSU	Secondary Sampling Units
SUPARCO	Pakistan Space and Upper Atmosphere Research Commission
TDS	Technical Demonstration Site
THEOS	Thailand Earth Observation Satellite
TM	Thematic Mapper
UAV	Unmanned Aerial Vehicle
UNECA	United Nations Economic Commission for Africa
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
VBA	Visual Basic for Applications
VMS	Village Master Sampling
WISE	World Inventory of Soil Emission potentials
WS	Wide Swath

Executive summary

The Expert Meeting on "Crop Monitoring for Improved Food Security" was organized at the initiative of the **Food and Agriculture Organization of the United Nations (**FAO) as a side event of 25th Session of the Asia and Pacific Commission on Agricultural Statistics on 17 February 2014 in Vientiane, Lao PDR, in close collaboration with the Asian Development Bank (ADB). The meeting was foreseen as contributing to one of the research areas identified under the Global Strategy to Improve Agricultural and Rural Statistics.

The Expert Meeting brought together over 40 experts from countries in the Asia and Pacific region, research institutions and international organizations to share their expertise and experience with a view to recommend use of latest methodologies and technologies in diverse country situations in the region. Sixteen technical papers were presented in three sessions. To conclude, a panel discussion of the Session Chair and Country Representatives was organized.

The meeting essentially focussed on the themes relating to: (1) Estimation of land cover, land use and crop area; (2) Crop yield monitoring and forecasting; and (3) Crop yield estimation using probability surveys and objective measurements. Outputs expected from the meeting were:

- Presentation and discussion of advanced methods and tools;
- Technical review of current practices with a view to identifying the suitability of methodologies in different situations; and
- Identification of best practices and methodological issues for further research.

The meeting concluded that:

- RS forecast of crop acreage and production is useful as advance information to the policy planners even if it is available with slightly lesser accuracy. RS is suitable for making in-season crop acreage forecasts and to provide monthly crop outlooks to planners and policy makers. It may be a particularly useful tool for countries with higher food security risks in taking ameliorating measures much in advance.
- In certain respects RS-based methodologies have distinct advantage, e.g. in providing rapid objective assessments without an investigator bias, longitudinal assessments (reporting changes over time at the same location), providing assessments on the hostile terrains, and rapid assessments of the extent of drought- and flood-affected areas.
- The use of information and communication technologies (ICT) like the GPS applications in smart phones, Google Earth imagery as a data source for area sampling frame, space-based technology, computer software applications for automating data processing and estimation should be considered in improving methodologies for crop monitoring.
- A wide range of methods and technologies are available to countries to adopt and combine with their current practices. The right mix of technologies should be based on the desired output and outcome requirements, absorptive capacity of the institution, and the resources that are available.
- Methods based on freely available remotely sensed data, like dot sampling method and ALIS, are quite simple to use, cost-effective and do not require much infrastructure and manpower. These are more suited to countries with relatively weak infrastructures to organize sample surveys or countries where even administrative reporting systems for agricultural statistics do not exist. While these methods are more suitable for generating land use information which does not change frequently, these can also be equally applicable for estimation of crop areas. For crop acreage, these methods may provide reliable estimates with a reasonable degree of precision in such countries.

- The use of RS in crop yield forecasts is still in the experimental stage. The use of RS products such as leaf area index and NDVIs is being explored to improve crop yield modelling and is an area for further research.
- While the use of remote sensing in deriving crop area estimates and measuring the impact of natural disasters has been proven to be beneficial in some countries, national statistical systems should be careful in adopting it as a full replacement of their traditional field data collection methods for crop monitoring. As staff skills are still being developed and various aspects of institutionalizing the use of remote sensing in official agricultural statistics have not been fully studied, remote sensing can be used to supplement and/or validate data collected using the current practices.
- Beyond estimating land use statistics, crop area, production and yield, crop monitoring also involves understanding the perception of farmers, their economic and social profile and the agricultural practices followed by them. These data and information are best collected using the traditional method of personal interviews.
- National statistical systems will greatly benefit from developing strong partnerships with local research institutions and space-technology agencies in institutionalizing data collection methods requiring ICT.
- In the long term, space-based technology and other ICT should be part of the tertiary school's curriculum, so that future generations will have a better understanding of these technologies.

Part I

Report

Introduction

The Expert Meeting on Crop Monitoring for Improved Food Security was organized by the FAO Regional Office for Asia and the Pacific (FAORAP) in collaboration with the Asian Development Bank (ADB) on 17 February 2014 in Vientiane, Lao PDR, as a side event of the 25th Session of the Asia and Pacific Commission on Agricultural Statistics (APCAS).

The objective of the Expert Meeting was to share best practices and experiences in the use of Remote Sensing (RS) technology and other similar tools for crop monitoring, area estimation and yield forecasting. About 50 experts and participants from governments, national and international organizations attended the meeting. The full List of Participants and Session Timetable of the meeting are Annexed in Part I of the publication.

The meeting essentially focussed on the themes relating to: (1) Estimation of land cover, land use and crop area; (2) Crop yield monitoring and forecasting; and (3) Crop yield estimation using probability surveys and objective measurements. Outputs expected from the meeting included:

- Advanced methods and tools tried in the countries in the region for improving crop forecasting and estimation of methodologies presented and discussed;
- Best practices and country experiences on use of the latest technological tools shared;
- Technical Review of current practices and methodological issues related to the practices in the region with a view to identifying the suitability of methodologies in different situations and areas for further research.

I. Opening session

The meeting commenced with the opening address of Mr Hiroyuki Konuma, Assistant Director-General and FAO Regional Representative for Asia and the Pacific, read by Mukesh K. Srivastava, Senior Statistician, FAO RAP. In his address, Mr Konuma stressed the importance of availability and better quality of agricultural and rural statistics for monitoring the food security situation and the need to exchange ideas and share best practices within the Asia and the Pacific countries to improve upon their agricultural statistical systems. Mr Savanh Hanephom, Deputy Director General, Ministry of Agriculture and Forestry, expressed a warm welcome to all the participants and thanked ADB and FAO for choosing Vientiane as the venue for the meeting.

In his opening remarks, Mr Douglas H. Brooks, Assistant Chief Economist, ADB, thanked the Government of Lao PDR for their hospitality and highlighted the importance of accurate data for evidence-based decision making in the agriculture sector. He shared his views on the issues impacting the status of agricultural statistics in the Asia and Pacific region such as assessment of the increasing demand on natural resources to produce more, declining national responses to meet increasing national and international data needs, assigning its due role to new technology in improving the situation, and improvements needed in the administrative reporting systems. He stressed that sustainable food security is of prime importance to ADB and described the research projects being funded by the organization in various countries which have helped them to improve their data collection methods.

II. Session 1: Estimation of land cover, land use and crop area

The session was chaired by Ms Dalisay S. Maligalig, Principal Statistician, ADB. The following presentations were made during the session.

1. Dot sampling method for area estimation (Issei Jinguji)
2. Agricultural Land Information System (ALIS) Program (Shoji Kimura, AFSIS)
3. Adoption of ALIS for agricultural area estimation (Mr Romeo Recide, Philippines)
4. Agriculture with satellite remote sensing and sensors (Preesan Rakwatin, GISTDA, Thailand)
5. A new method to estimate rice crop production outlook using earth observation satellite data (Toshio Okumura, RESTEC, Japan)

The main points made in these presentations and following discussion are reported below.

Dot sampling method

Mr Issei Jinguji (independent expert) presented the background, methodology, operational procedures and the precision obtained in use of the dot sampling method. This method allows selection of a sample without the requirement of a list-based sampling frame. Each sample point (dot) on the ground is identified by its coordinates (latitude, longitude), and the practitioner has to only check the land usage at the sample dot. Sample dots can be selected systematically using a random start and interval based on sample size. Macro programmes are available which enable generation of the sample directly in the excel sheet called the "sample dot sheet" for an area survey using commonly used sampling techniques such as simple random sampling, systematic random sampling, etc. Each dot on the sheet represents the location of the sample point on the ground and can be easily identified by their longitude and latitude on the ground during the field survey. This excel sheet, when overlaid on the satellite imagery like the one provided by Google Earth of the survey area, leads to the selection of plots/fields represented by dots with probability proportion to size. Macro programmes are available to display the sample dots directly on the Google Earth. The next stage in the method is to carry out a land use survey on Google Earth by visual observation and observe land use categories such as agriculture or non-agriculture land.

The methods can also be used for crop area enumeration surveys. The method provides efficiency of fieldwork as the enumerators need to visit only sample dots identified as cultivated land and visits to non-agricultural sample dots may be avoided. Identification of cultivated land and crop area is done by overlaying the sample points on available satellite imagery. This is followed by the actual field survey process for recording the land use at the sample dot. The frequency distribution of sample dots is generated as per land use categories of interest including crop area, which when multiplied by the total survey area gives the estimate of land use under each category as well its standard error. Therefore the method can estimate not only core crops area but also minor crops area and dyke area rapidly in a whole target area (population) in every crop season in a year. It is interesting to note that there are no measurements involved in the method and it is therefore free from measurement-linked non-sampling errors.

Agricultural Land Information System (ALIS)

Mr Shoji Kimura from AFSIS presented ALIS software which enables estimating agricultural land and crop area in situations where conducting large scale sample surveys is not found feasible due to constraints such as manpower, finance and availability of information for planning the survey or drawing of representative samples. The methodology used in the system involves estimating the agricultural land area of the most recent period for which a reasonably detailed satellite map is available. The whole map is divided into meshes to reflect the mother population (universe of study). A reasonably large sample of meshes (master sample) is closely observed on the map to identify the land use. This leads to an estimate of the agricultural area for the reference period of the map. A sub-sample from the master sample is taken for actual field observation during each season to estimate the change in area, as well as the area under each of the target crops This estimated change in agricultural area is applied to the estimates prepared using the master sample of meshes. The estimates of area under different crops are prepared on the basis of use of agricultural area by different crops observed in the sample meshes.

Use of ALIS for agricultural area estimation in Philippines

Mr Romeo Recide, Philippines, presented the practical experience in application of the ALIS method for estimating crop acreage in Philippines. Based on the results obtained it was suggested that ALIS can provide a reliable estimate of total agricultural land area. The estimate for rice planted areas in the province of Nueva Ecija was also considered reliable, but the estimates of planted areas for other crops was not so reliable. *It was therefore recommended that the ALIS software should allow for stratified SRS sampling of meshes so that areas planted to other crops can be better estimated. The software should also provide the option of classifying meshes according to types of crops in addition to the categories of agricultural vs. non-agricultural land and software should be open to receive data sources other than Google Earth.*

Use of satellite remote sensing and sensors in Thailand

Mr Preesan Rakwatin, GISTDA, Thailand, presented the use of remote sensing technology for crop monitoring in Thailand using field server and satellite remote sensing technology. The presentation highlighted the ability of remote sensing in identifying crops on the field and in detecting changes and classification of agricultural produce. The study also showed the capability of the technology in distinguishing the single crop and multi-crop planting patterns on the ground. This was possible because the crop signatures (remote sensing signals) are different for these cropping patterns. In addition, *in situ* data is necessary for calibration and validation of the product derived from satellite images. Since collecting *in situ* data is costly and time consuming, field server (FS) technology was used to collect field data. FS is an Internet Field Observation Robot that consists of a set of multiple sensors, a web server, an Internet Protocol (IP) camera, as well as wireless interfaces. It is designed to provide an outdoor solution for environment monitoring.

Rice crop production outlook using earth observation data

Mr Toshio Okumura, RESTEC, Japan presented the use of Synthetic Aperture Radar technology for estimating rice acreage and yield in situations of cloud cover when optical data is not available during the rainy season. The presentation highlighted that since Earth observation satellites can observe large spatial extents at high temporal frequency and in high quality for reasonable cost, they are a very powerful tool for agricultural monitoring at national and provincial levels in Japan. For agricultural monitoring of crops including corn, wheat, and soybean, time series of optical data from missions such as Landsat are commonly used to estimate crop area and production efficiently. However, Asian rice crops are generally grown during the rainy season (monsoon season); the limitation of optical sensors to penetrate cloud cover in rainy weather conditions poses a challenge to estimating paddy area and rice production. *Space-based Synthetic Aperture Radar (SAR) based on microwave frequencies is a useful alternative for rice crop monitoring, as it can penetrate cloud cover/rain to give accurate information of the Earth's surface.* SAR is used to complement optical sensor data to estimate the rice crop area and production in Asia. In this technology, SAR instruments emit a microwave signal and receive the echo (the microwave backscattered signal) from the ground. When newly planted, rice weakly backscatters the signal to the satellite because of minimal polarisation (specular reflection), and the SAR data image becomes dark (low count value). At a well-grown stage, the microwave backscatter becomes strongly polarised, and the brightness of the image increases. Thus, using the well-established relationship between backscatter and crop growth stage, the rice crop area can be estimated. The accuracy of estimated rice crop acreage was stated to be more than 90 percent of the field survey value.

Discussion

In the discussions that followed the presentations, participants raised issues relating to the suitability of the presented methods in different situations. It was observed that both the dot sampling and the Agricultural Land Information System (ALIS) methods are apparently similar, simple to use and relatively cost-effective as they are based on freely available satellite imageries and maps. However, the differences in the two methods need to be noted. While ALIS method works with Google imageries for classifying geographical areas into various land use categories and identifying the cells of the mesh blocks which define the sampling frame, the dot sampling method uses Google Earth to identify the selected sample points on the ground. Both methods involve ground surveys, but the extent of field enumeration differs. The ALIS method involves verifying only a sub-sample of selected meshes for verification of findings on the basis of observation from satellite imageries, while the dot sample methods requires visiting each selected sample point for finding the facts on the ground. Obviously, the precision of both the methods will depend largely on the sample size used for verification on the ground, which also has cost implications.

The dot sampling method is basically a survey of attributes of the landscape using Google Earth and is best suited in country situations which are at the very early stage of statistical development, i.e. lacking statistical infrastructure like sampling frames and resources to conduct a properly designed sample survey. Though the dot sampling technique has been developed to work with Google Earth only, the use of satellite imageries and hybrid maps which contain topographic information as well can potentially improve the efficiency of dot sampling, as one has the option of eliminating the clearly identified sampling points from the list of points for ground verification. The point falling on clearly non-agricultural area can be substituted in the laboratory itself. This enhances the efficiency of sampling within the given budget constraints when a preparatory survey is included in the process.

The dot sampling method can work with reasonably recent satellite imageries or maps; the reliability of results does not depend much upon the age of the imageries as it involves ground verification at sample dots on cultivated land. The ALIS software on the other hand relies much on the currency of the maps and carries out verification on a small sample to calibrate the estimates from maps.

It was noted that remote sensing technology is being used as a tool to obtain information for monitoring crop conditions and for acreage and production forecasting for making policy decisions relating to food security in many countries. In some countries, remote sensing applications currently in use were still in the experimental stage with an accuracy level for crop acreage forecasts ranging from 70-90 percent, which varied with the type of crop and its dispersion on the terrain. Further work is needed to make these methods operationally useful at the national level.

III. Session 2: Crop yield monitoring and forecasting

The session was chaired by Mr John Latham, Senior Land and Water Officer NRL Division, FAO. The following presentations were made during the session.

1. Crop watch introduction and crop area estimation (Bingfang Wu, Chinese Academy of Sciences (CAS), the People's Republic of China)
2. Pakistan satellite-based crop monitoring and forecasting system (Ijaz Ahmed, SUPARCO, Pakistan)
3. Use of remote sensing technology in crop monitoring and assessment of impact on natural disasters (S.S. Ray, National Crop Forecast Centre, India)
4. Remote sensing-based crop yield monitoring and forecasting (Tri D. Setiyono, IRRI)
5. Satellite-based crop monitoring & estimation system for food security application in Bangladesh (Hafizur Rahman, SPARRSO, Bangladesh)

The findings of experts from the People's Republic of China, Pakistan, India, Bangladesh, and IRRI were presented and specific country experiences were highlighted. These are reported below.

People's Republic of China

The People's Republic of China (PRC) has made significant advances in the use of remote sensing technology to monitor the global, regional and national level agricultural and environmental situation. Global environmental analysis is carried out using remote sensing data on temperature, radiation, rainfall and related variables. This facilitates the compilation of indices such as the Environmental Index, Cropping Intensity, Vegetation Health Index, and Drought Index. Crop watch bulletins are generated and disseminated through its official website "Crop Watch" on a regular basis. Crop watch is mainly based on remote sensing data and provides crucial information to the central government.

For estimating crop acreage, the Crop Planting and Type Proportion (CPTP) method is used wherein the geographical area is stratified according to climatic zones, planting structures and farming density and crop proportions are obtained for these strata using specialized field instruments. The sampling unit for RS data is 4 × 4 km square grids. Optical data (photos) of sampling units are taken to classify the area into crop and non-crop areas which are then, using crop proportions, further classified into major crop categories. Validation is carried out by ground surveys. Since there are only four major crops in the PRC, it is relatively easy to identify them. However, the accuracy level is stated to be low for minor crops.

Pakistan

In Pakistan, SUPARCO has been using satellite-based area frame sampling, a fully operational system for the estimation of crop areas, since 2007. The Satellite-Based Area Frame technique uses a three-stage stratification process to delineate homogenous areas in order to use statistical procedures to estimate crop areas. Use of smart phones for ground data collection helps in validation of crop forecasts. Crop yield is also a major component for the crop production forecast and estimation in Pakistan. Statistical models are being used by SUPARCO for the estimation of the yield using a number of parameters such as weather, fertilizers, irrigation and remote sensing indices. For information sharing, Pakistan issues a monthly crop bulletin, publications on rapid crop damage assessment (floods/droughts) and related technical reports.

India

In India, a new institution (Mahalanobis National Crop Forecast Centre) has been established to meet the in-season crop assessment requirements of the Ministry of Agriculture. The Centre is responsible for generating RS-based multiple forecasts on crop acreage and production for selected crops during the season and to provide monthly assessments of the drought and flood situation in the country.

The forecast methodology uses both microwave and optical data and is designed to provide 90 percent area coverage with 90 percent accuracy. For acreage forecasts, stratified random sampling is adopted wherein square grids of 5 x 5 km are first stratified into 4 strata based on crop proportions (>75 percent, 50-75 percent, 25-50 percent and <25 percent) based on past data. A sample of 20 percent square grids is selected in each stratum and RS data of selected sampled grids are classified into crop types using multi date data and estimates obtained. Satellite images are captured at intervals of about 20-25 days and 3 in-season forecasts are made.

Along lines similar to Google Earth, India has developed its own platform "Bhuvan" to help develop thematic applications in various sectors. Bhuvan is also being used for uploading real time ground truth data collected through smart phones by MNCFC officials. For estimating crop yield, econometric and agro-met models have been developed which are used in conjunction with RS acreage data to forecast crop production. Development of crop yield simulation models and spectral models are in the experimental stage. RS data is also utilized to assess the drought situation and monthly drought assessment reports are generated and disseminated.

IRRI

The presentation discussed the project "Remote Sensing-based Information and Insurance for Crops in Emerging Economies (RIICE)" which is a public-private partnership project aiming to reduce the vulnerability of rice smallholder farmers in low-income Asian countries using synthetic aperture radar (SAR) technology. SAR data is used to map and observe rice growth, and together with a crop growth model, the technology allows prediction of rice yield in selected rice-growing regions in Cambodia, India, Indonesia, Thailand, the Philippines and Viet Nam. The use of SAR technology is crucial given that cloud obstructed views from space are common phenomena for the region due to the cloud insensitive feature of radar-based earth observation. *National partners in the countries covered by RIICE provide expert knowledge and baseline data, and conduct fieldwork and monitoring of sites.*

IRRI undertakes rice yield forecasts based on a crop growth simulation model using a combination of real-time and historical weather data such as daily solar radiation, daily minimum and maximum temperature, daily average wind speed, rainfall data and SAR-derived key information such as the start of the growing season and the leaf growth rate. Results from pilot study sites in South and Southeast Asian countries suggest that incorporation of remote sensing data (SAR) into process-based crop models improves the yield estimation for actual yields and thus offers potential application of such system in a crop insurance programme. Remote sensing data assimilation into the crop model effectively captures the responses of rice crops to environmental conditions over large spatial coverage, which is practically impossible to achieve with the crop modeling approach alone.

Bangladesh

In Bangladesh, SPARRSO has developed Decision Support Systems which help the government monitor the agricultural situation and the impact of natural disasters. In agriculture, small holding sizes and spatial heterogeneity makes crop monitoring a challenging task. RS methodology has been developed for estimation of rice acreage and yield assessment is done using normal statistical procedures. Both moderate and high resolution RS data are used for crop acreage forecasts and ground truth is collected using GPS instruments.

Discussion

The discussion concluded that RS technology is capable of providing acreage forecasts for rice and other major crops, can generate crop outlooks, assess the drought and flood situation and help governments make timely policy decisions on issues related to food security. However, for minor crops and cash crops, methodological improvements are needed to make their forecasts operationally useful. *The problem of cloud cover is significant for short duration crops and may impact the quality of forecasts due to data loss. For long duration cash crops such as cotton and sugarcane, multiple date data helps overcome this problem and the issue of data loss is not a major problem.*

Besides area and production data, RS inputs such as the leaf area index and chlorophyll content/crop condition are also finding applications in crop yield modelling, in stratification of statistical units for optimizing sample size at national and sub-national levels and in preparing crop outlooks and market monitoring progressively with the season.

It was observed that RS methodologies to forecast area coverage and yield are available for only a limited number of major crops while countries require information on a large number of crops. *Remote sensing therefore cannot replace the traditional methods used in statistical systems which capture data on a large number of crops. Remote sensing also cannot capture the socio-economic data on agricultural practices of the agricultural households which can be obtained through traditional methods of personal contact.* Use of Synthetic Aperture Radar (SAR) technology was stated to have helped overcome the problem of loss of satellite data due to cloud cover during the rice season.

Limited availability of RS data and the higher cost of better resolution satellite data are other major constraints for their wide spread use in many countries. It was suggested that use of open source data may help in making the technology cost-effective and free access to 10 m resolution satellite data is a distinct possibility in the near future.

IV. Session 3: Crop yield estimation using probability surveys and objective measurements

During the session, chaired by Ms Sarah Hoffman, USDA, the following presentations on country experiences on objective yield assessment through crop cutting experiments (CCE) were presented during the session:

1. Rice objective yield survey in Japan (Masahiro Hosaka, Japan)
2. Sampling frame of square segment by points for rice area estimation (Mubekti Munandar, Indonesia)
3. Experience of crop cutting experiments in Thailand (Supaporn Bongsunun, Thailand)
4. Recent experiences of sample crop (rice) cutting in Bangladesh (Bidhan Baral, Bangladesh)
5. Agricultural survey improvement programme in Islamic Republic of Iran (Mehrdad Nematzadeh Alidash, Iran)
6. Promote the application of spatial information technology in crop production survey (Ge WEI, the People's Republic of China)

The highlights of the papers are reported below.

Japan

Objective yield forecasts and estimates of crop yield based on yield forecast models and Crop Cutting Experiments (CCEs) are designed to achieve a standard error of 1 percent. The methodology requires the collection of ancillary information during the growth stages of crops every month, finally culminating in the conduct of CCEs. The number of crop cuts is decided based on the observed coefficient of variation and desired level of precision. Monthly data on a number of crop characteristics such as plant height, number of leaves, flowers, pods, grains, etc., depending on crop type are collected and used in crop forecast models to generate yield. The crop situation index is calculated by comparing the forecast yield with the normal yield. To overcome the manpower constraints for conducting a large number of CCEs, a number of changes have been introduced in the yield assessment methodology such as reduction of the number of CCEs from 34 000 to 10 000, and changing the crop cut size from 9 m^2 to 3 m^2. Methodological improvements have also been made in obtaining normal yield through trend analysis by removing the effect of meteorological factors.

Indonesia

Area frame sampling is one of the methodologies recommended for obtaining rice acreage and production. Based on the available land use data, the geographical area is classified into 3 strata viz. 1) rice, 2) possible rice and 3) non-agriculture land. For estimation of rice acreage, stratas 1 and 2 are divided into 10 km × 10 km blocks for sampling purposes. Each block is further subdivided into 400 square segments of 500 m × 500 m size. In each block, samples of 10 segments (2.5 percent) are selected with systematic random sampling using distance threshold and assigned a code number and geographical coordinates for identification. Each selected segment is further divided into 25 sample points/cells of 100 m × 100 m each and the centre of each cell will be the point for field observation and recording the growth stage of rice in each cell such as vegetative, generative, harvested, fallow, etc. The sample information is submitted by the investigators through SMSs, thereby speeding up the crop forecast. This sample information and the sample design make it possible to estimate the rice acreage and the likely area to be harvested during the next two months. The main advantage of this method is that it allows sample selection without constructing the sample frame.

Thailand

To estimate area planted, yield and production of crops, production surveys are conducted using the household approach. The process involves preparation of a list frame of households, selection of sample households and conducting interviews with them and preparing a sketch of all paddy fields of the selected household. For better estimation of crop yield, CCEs, dyke surveys and gleaning surveys are also conducted.

The presentation described the implementation procedure for the crop cutting experiments conducted in Thailand for estimating rice yield in the country. The process begins with using the list of sample villages available with the office of Agriculture Economics based on past surveys. Depending upon the precision to be attained, a number of experiments are planned and executed. This involves selection of the sample villages, identification of rice growing households in the selected village, selecting three such households per village, identifying the household's rice fields ready to be harvested within a given time period, preparing a map of the fields, and selecting one rice field using a random number table. Provision for the substitution of households also exists in case the selected household is not ready to harvest the rice fields.

In the selected field, the first plot of size 1 m x 1 m is located 30 steps length-wise and breadth-wise inside the field from the lower left corner of the field. Similarly, the second plot is also located 30 steps inside the field starting from opposite diagonal end of the field. Actual demarcation of the plot is done by placing a frame of size 1 m x 1 m at the sample location parallel to the ridge of the field. Crop stalks within the frame are harvested for estimating yield. Households are subsequently followed up to record the actual yield harvested by them from the selected entire field. It is generally observed that the yield obtained through CCEs is higher than the yield harvested by the household mainly because of the losses during the harvest and the presence of the non-crop areas such as bunds/dykes/wells, trees, etc., in the fields. *The yield from the CCEs therefore needs to be adjusted to account for such uncultivated aresa and harvest losses.*

The methodology for the gleaning survey is the same as for the CCEs. The same rice fields are visited after the crop is harvested by the household, plots of 1 m x 1 m are selected and the rice grains left within the frame are collected and weighed before any ducks, mice, etc., come into the field. Similarly, a dyke survey is conducted to obtain the uncultivated area ratio (uncultivated area/total area of the field including dyke). The total area is obtained by measuring the planted area with the dyke using the tape measuring method. The uncultivated area is obtained by measuring the length and breadth of the dyke to arrive at the area of the dyke using Heron's method/Offset method.

Bangladesh

Bangladesh Bureau of Statistics (BBS), Department of Agriculture Extension (DAE) and SPARRSO are three organizations engaged in producing statistics on crop production. Traditionally, there have been differences in the estimates produced by them. In order to overcome the problem of conflicting statistics, a project on harmonization and dissemination of unified crop production statistics has been conceptualized and implemented with FAO support for rice, which is the important staple crop in the country. On the basis of collaborative research undertaken by BBS and DAE, it was concluded that both DAE (following the rectangular plot approach) and BBS (following the circular plot approach for crop cutting experiments) overestimated the yield. Based upon research evidence it was found that a plot size equal to 20 m^2 provides more accurate estimates of crop yield. Based on these conclusions, Bangladesh has adopted circular crop cuts of 20 m^2 for conducting crop cutting experiments. Teams of all the stakeholders monitor these experiments in the field and the data is processed on computers in a transparent way. As a result of this project, it is now possible to avoid conflicting statistics from various sources on rice crops. A similar approach may be needed for other important crops.

Iran

Both list and area frames are used to generate agricultural statistics – the list frame for livestock and services and the area frame for acreage of crops and orchards. Stratification of land cover in the categories of irrigated agriculture, rain-fed agriculture, orchards, rangelands and non-agricultural land is made and sample segments are selected from each strata (except from the non-agricultural strata) and details of operators in each segment and their holdings, crop type and coverage, etc., is collected for estimation of acreage under various crops. The presentation identified the availability and accessibility of remotely sensed data as a major issue for its potential use. Because of international sanctions against Iran, ordering and purchasing satellite data is very difficult.

People's Republic of China

The use of three technologies – RS, GIS and GPS – to collect information from sky, ground and people was demonstrated. The basis of the data collection is the area frame survey. The frame is constructed using inputs from the agriculture census, land surveys and RS. The smallest unit for the area frame survey is the elementary sampling unit (ESU) comprising of 2-5 ha of land; the village is taken as the primary sampling unit (PSU) which has been digitally mapped using high resolution RS data. For survey purposes, PSUs are selected with probability proportional to size and within each PSU, ESUs are selected using simple random sampling. Data collection includes a one-time survey of all the selected PSUs/ESUs collecting their locational and other basic information. Field surveys are undertaken using GPS and PDAs. Sampling errors of the estimates are arrived at by using Jackknifing method.

V. Panel conclusions

The three session chairs, Mr Douglas Brooks, ADB, Mr John Latham, FAO and Ms Sarah Hoffman, NASS, USDA and the three country representatives, Mr Romeo Recide, Philippines, Mr Shibendu Shankar Ray, India and Mr Kenji Kamikura, Japan comprised a panel and were invited to reflect on the themes covered by the meeting.

Mr Latham stated that although conventional methods are robust, new technology offers the advantage of being as precise but more timely. A combination of methods will thus have many advantages. Many countries in the Asia and Pacific region have made great progress in the use of RS, GIS and GPS and there is good scope for building on these resources. He also stressed the use of multiple frames for meeting growing data demands at national, regional and global levels.

Mr Kamikura stated that developing countries are facing restrictions such as lack of resources (both human and financial), the planning area changes year by year, the absence of land registration, etc. Concerning RS technology, it sounds like it would be effective but its actual application to collecting crop data faces restrictions such as difficulties in identification of planting crops and a lack of budget. For rapid appraisal of the area planted or for monitoring the area planted repeatedly over the year the dot sampling method seems promising. The method can be applied repeatedly over different seasons as well.

Ms Hoffman stated that all the methodologies and technologies discussed in the meeting are useful but the countries need to adopt them depending upon their budgets and after exploring their suitability.

Mr Recide stated that the existing procedures of estimating area, production and yield data are serving well but there is also greater scope to improve these methods using the latest tools. In many countries where traditional estimates have limitations, RS can play a vital role in improving these data.

Mr Ray stated that RS has a major advantage in that it depicts relative changes in the crop situation through pictures/images and the user is able to relate to them easily. He stressed that RS data and traditional data need to play complementary roles by providing in-season assessments through RS and final estimates through surveys. Considerable work has taken place in acreage estimation but more work is needed in yield forecasting using RS technology. The availability of RS data needs to be promoted so that low cost data is available to the users. In India, institutionalization of RS in the Ministry of Agriculture (user agency) has helped in harnessing its potential use in other applications such as drought and flood assessment, disease and pest surveillance, land use mapping, identifying cropping patterns and crop calendars.

In the ensuing discussions, participants raised a number of issues such as the accuracy level of RS forecasts, replacement of traditional methods by RS, cost effectiveness of the two approaches, country experiences in actual operationalization of the RS approach at the country level, its utility in addressing crop yield estimation, reducing the number of CCEs through improved stratification, etc.

At the end of the discussion, Mr Brooks summarized the discussions, enumerating the range of methodologies available and the need for countries to make choices to use them as per their requirements and situation. He stressed that both the approaches should be seen as complementary and not conflicting with each other through the optimal use of the strengths of each. He also stressed that there is a great scope to build the capacity of countries in the utilization of latest technological tools.

The conclusions of the meeting were presented to the 25th Session of the Asia and Pacific Commission on Agricultural Statistics (APCAS 25). These included:

- RS forecast of crop acreage and production is useful as advance information to policy planners, even if it is available with slightly lesser accuracy. RS is suitable for making in-season crop acreage forecasts and providing monthly crop outlooks to planners and policy makers. It may be a particularly useful tool for countries with higher food security risks in taking ameliorating measures much in advance.
- In many countries, the use of remote sensing technology for agricultural monitoring has shown remarkable progress. In certain respects, RS-based methodologies have a distinct advantage, e.g. in providing rapid objective assessment without an investigator bias, longitudinal assessments (reporting changes over time at the same location), providing assessments on hostile terrains, and rapid assessments of the extent of drought- and flood-affected areas.
- The use of information and communication technologies (ICT) like the GPS applications in smart phones, Google Earth imagery as a data source for area sampling frame or a means for putting sample dots on a map, space-based technology, computer software applications for automating data processing and estimation should be considered in improving methodologies for crop monitoring.
- A wide range of methods and technologies are available to countries to adopt and combine with their current practices. The right mix of technologies should be based on the desired output and outcome requirements, absorptive capacity of the institution, and the resources that are available.
- Methods based on freely available Google Earth imageries and maps, like dot sampling method and ALIS, are quite simple to use, cost-effective and do not require much infrastructure and manpower. These are more suited to countries with relatively weak infrastructures to organize sample surveys or countries where even administrative reporting systems for agricultural statistics do not exist. While these methods are more suitable for generating land use information which does not change frequently, these can also be equally applicable for estimation of crop areas. For crop acreage, these methods may provide reliable estimates with a reasonable degree of precision in such countries.
- The use of RS in crop yield forecasts is still in the experimental stage. The use of RS products such as leaf area index and NDVIs are being explored to improve crop yield modelling and is an area for further research.
- While the use of remote sensing in deriving crop area estimates and measuring the impact of natural disasters has been proven to be beneficial in some countries, national statistical systems should be careful in adopting it as a full replacement of their traditional field data collection methods for crop monitoring. As staff skills are still being developed and various aspects of institutionalizing the use of remote sensing in official agricultural statistics have not been fully studied, remote sensing can be used to supplement and/or validate data collected using the current practices.
- Beyond estimating land use statistics, crop area, production and yield, crop monitoring also involves understanding the perception of farmers, their economic and social profiles and the agricultural practices followed by them. These data and information are best collected using the traditional method of personal interviews.
- Research institutions, space technology agencies and national statistical systems should continue to regularly exchange ideas and experiences for improving crop monitoring.
- National statistical systems will greatly benefit from developing strong partnerships with local research institutions and space-technology agencies in institutionalizing data collection methods requiring ICT. In the long term, space-based technology and other ICT should be part of the tertiary school's curriculum, so that future generations will have a better understanding of these technologies.

Annex 1: Opening addresses

1. Opening address

Hiroyuki Konuma
Assistant Director-General and FAO Regional Representative for Asia and the Pacific

Distinguished Experts, Participants and Representatives from Partner Institutions, Ladies and Gentlemen,

It gives me immense pleasure to extend a warm welcome to all the distinguished experts and participants from premier institutions in the region attending this meeting on *Crop Monitoring for Improved Food Security*. First of all, I wish to express our special gratitude to the Government of Lao PDR for hosting this important gathering here today. I am happy to note that over 40 experts from many countries within and outside the Asia and Pacific region have come together to support the cause of improving agricultural statistics for the eradicating hunger and malnutrition.

I am thankful for your keen interest in the themes of the meeting and for travelling long distances to participate in this event despite your busy schedule. FAO and ADB are privileged to host you and benefit from your expertise and long experience in this area. Working together, sharing and pooling knowledge with you will indeed have a lasting impact on the methods being practiced in countries of this region for producing reliable and timely estimation of crop production, and for monitoring of crop condition to ensure timely action for ensuring food security.

I am delighted to acknowledge the ADB's acceptance of our request to jointly organize this event with FAO, and its contribution to this meeting at a very short notice. I am also thankful to other international organizations like AFSIS and IRRI, and national institutions like GISTDA, NCFC, SPARRSO, SUPARCO, JAXA, and the important institutions from the People's Republic of China, Indonesia and Iran for their deep interest and technical contribution to this event.

Ladies and Gentlemen,

FAO is mandated to combat hunger, food insecurity and malnutrition which is our first strategic objective. FAO is the lead agency to monitor the progress towards achieving the Millennium Development Goals (MDG) hunger indicator, aiming to reduce the proportion of undernourished people by half by 2015. Besides eradication of hunger, food insecurity and malnutrition, FAO's new Strategic Objectives focus on sustainability of agriculture, reduction of rural poverty, and increasing resilience of livelihoods to threats and crisis. Above all, our activities are now to be aligned to meeting the "Zero Hunger" challenge.

I am sure you will all agree that availability of precise and timely information on the demand and supply of agricultural production is crucial to our fight against hunger, food insecurity and malnutrition. This meeting is, therefore, of particular importance to FAO as it will assist member countries to build their capacities to produce timely and reliable information for mitigating food insecurity related risks and for planning necessary government interventions and programmes.

Incorporation of latest technological tools such as GIS, remote sensing, GPS instruments and PDAs in the data collection methods will not only bring about an improvement in quality and reliability of data available at national level but also go a long way in meeting regional and international data requirements for better development outcomes.

I am glad to see that the meeting has kept a specific focus on the use of remote sensing technology which has tremendous potential in conjunction with statistical methodologies. It has important use in estimation of crop area and in forecasting yield, as well as for making rapid assessment of impact of natural disasters, such as drought and floods, on the livelihood of the affected people. In promoting the technology we need to be conscious of its cost-effectiveness and affordability for less developed countries.

Fellow Experts,

I am particularly keen to see that you come up with a critical review of information gaps, methodological issues and best practices available at the country, regional and global level, and your well-considered recommendations to FAO on the suitability of available techniques in diverse situations prevailing in the countries of the region.

I am confident that conclusions and recommendations of this one day expert deliberations will help member countries on the choice of the most appropriate methodology in their specific conditions using latest technology for improving the crop production data. Your conclusions will also help FAO and ADB to allocate resources to specific types of research required to develop and refine methodologies, which is one of the components of Global Strategy to Improve Agricultural and Rural Statistics.

Ladies and Gentlemen,

FAO values the regional partnership with ADB, ESCAP and SIAP in implementation of the Global Strategy, which is a long term effort. We now have a shared Regional Action Plan to improve agricultural and rural statistics. Though it has received initial donor support, more resources and partnerships need to be found for sustaining the activities foreseen in the plan in the long run. I hope this meeting will contribute to building new alliances for improving methodologies.

I can clearly see today's deliberations will contribute to one of the identified research priorities of the Global Strategy. I am sure your recommendations will assist countries in making critical choices in development of their Strategic Plans for Agricultural and Rural Statistics (SPARS), proposed as part of Technical Assistance component of the Regional Action Plan of the Global Strategy.

Ladies and Gentlemen,

Finally, let me acknowledge the hard work of the colleagues in ADB, and SAEDA together with those of FAORAP for the successful preparation and organization of this meeting.

I wish you all success in your discussions and a pleasant stay in Vientiane.

Thank you.

2. Opening remarks

Douglas H. Brooks
Assistant Chief Economist, Asian Development Bank

Experts and Colleagues:

Welcome to this meeting on crop monitoring for improved food security. It is our pleasure to partner with the Food and Agriculture Organization of the United Nations (FAO) in organizing this meeting, as a side event to the 25th Session of the Asia and Pacific Commission on Agricultural Statistics (APCAS). We believe that this meeting offers an excellent venue for experts and researchers from participating countries and international organizations to exchange ideas to address the challenges in crop estimation and forecasting.

Agriculture is still the major source of employment in many countries in this region. And a majority of the poor live in rural areas, where agriculture is still the main source of livelihood. To achieve inclusive growth, therefore, agriculture and rural areas must be developed and the effects on future food security of population growth, demand for natural resources and competing food crop use, and extreme weather and climate change must be understood and taken into account. For these issues to be examined and appropriate policies to be formulated there must be accurate, timely, reliable, and comprehensive data on agriculture and the rural areas.

Many countries in the region do not yet have such data support systems for policy making and planning. Many still rely on administrative reporting systems that yield timely but often not reliable estimates only at specific levels of the government hierarchy. And there are few farm-level and household level data that can be used for policy analysis.

As we are aware, inaccurate estimation of staple food production can lead to inappropriate policies and, consequently, unfavorable outcomes, possibly worsening food security. To ensure that better development outcomes are achieved, we need data and other evidence as a foundation for crafting better and more relevant policies.

On the basis of the most recent FAO report, the country response rates to their annual questionnaires that collect data on production and land use, among others, have declined in recent years. Hence, it was quite timely that the United Nations Statistical Commission endorsed the Global Strategy to Improve Agricultural and Rural Statistics, and in our region for the FAO, the United Nations Economic and Social Commission for Asia and the Pacific, and the Asian Development Bank to work together with countries represented here today in developing and implementing the Asia and the Pacific regional action plan to support the Global Strategy.

For ADB, food security is one of the important underlying components for sustainable and inclusive economic growth. ADB has an Operational Plan for Sustainable Food Security in Asia and the Pacific that calls for a multi–sector approach to improve the productivity, connectivity, and resilience of food supply chains; enhanced partnerships; and increased but focused support for agricultural research. We are also implementing two technical assistance grants for improving agricultural and rural statistics in support of the regional action plan and the Global Strategy.

In all the stakeholder meetings that we conducted to help countries develop their action plans for improving agricultural statistics, stakeholders placed high priority on accurate and timely data for monitoring major crops that are critical to food security. In this regard, we have planned activities to help countries improve the design of their production surveys as well as their administrative reporting systems. Together with relevant statistical agencies in these countries we are studying existing data sources and compilation methods to identify and establish more effective systems for monitoring crop production. And we are conducting training programmes to improve sample survey design and operations.

We also looked beyond these two traditional methods and found that some countries and institutions in the region have adopted more advanced tools for measuring crop areas and monitoring production. For example, the International Rice Research Institute's study on the use of satellite imagery for micro cropinsurance purposes was recently used to accurately determine rice production losses in the central Philippines due to the super typhoon Haiyan. Researchers in IRRI studied a series of rice area maps that they constructed from satellite images before and after the typhoon for this purpose.

Unlike surveys that require a longer time for data collection and processing, estimates from well-established remote sensing software applications can be derived quickly. Successive area maps can be studied to determine changes in cropping patterns. This approach will therefore be beneficial for government planners who often require more frequent and time-bound data and information.

Because the application of space-based technology is still in its infancy at ADB, we forged partnerships with institutions who have more advanced knowledge in this area so we can better assist interested national statistical systems. We partnered with the ASEAN Food Security Information System project that developed the Agricultural Land Information System (ALIS) and the Japan Aerospace Exploration Agency (JAXA) that has explored the use of remote sensing for estimating rice area and production. The Philippines Bureau of Agricultural Statistics has estimated crop areas using Google maps and the ALIS software, courtesy of AFSIS. With JAXA's assistance, we are now working with four countries to plan and adopt the use of satellite imagery for estimating rice crop area and production.

These partnerships with FAO, ESCAP, AFSIS and JAXA are only a few examples of collaboration that can yield good results for improving agricultural and rural statistics. This meeting presents another opportunity for government representatives and experts to exchange ideas, learn from one another and initiate more collaboration for enhancing agricultural statistics.

We need to continue establishing strong partnerships so that agricultural and rural statistics in this region will flourish. Your presence in this meeting is an important indicator that we can act collectively. We hope that together, we can effectively share experiences, expertise, and resources in support of developing agricultural and rural statistics in this region.

Thank you.

Annex 2: Timetable

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

08.00 hrs.	**Registration**
08.30–08.45	**Opening session**
	1. Opening remarks by organizers (FAO and ADB)
	2. Introduction by participants
08.45–10.45	**Session 1: Estimation of land cover, land use and crop area**
	Chairperson: Ms Dalisay S. Maligalig, ADB
	1. Dot sampling method for area estimation (Mr Issei Jinguji)
	2. Agricultural Land Information System (ALIS) Program (Mr Shoji Kimura, AFSIS)
	3. Adoption of ALIS for Agricultural Area Estimation (Mr Romeo Recide, Philippines)
	4. Agriculture with Satellite remote sensing & sensors (Mr Preesan Rakwatin, GISTDA, Thailand)
	5. A new method to estimate rice crop production and outlook using Earth Observation satellite data (Mr Toshio Okumura, RESTEC, Japan)
	Discussions
10.45–11.00	***Coffee Break***
11.00–13.00	**Session 2: Crop yield monitoring and forecasting**
	Chairperson: Mr John Latham, FAO
	1. Crop Watch Introduction and Crop Area Estimation (Mr Bingfang Wu, Chinese Academy of Sciences (CAS), the PRC)
	2. Pakistan Satellite Based Crop Monitoring and Forecasting System (Mr Ijaz Ahmed, SUPARCO, Pakistan)
	3. Use of Remote Sensing Technology in Crop Monitoring and Assessment of Impact of Natural Disaster (Mr S.S. Ray, National Crop Forecast Centre, India)
	4. Remote Sensing based Crop Yield Monitoring & Forecasting (Mr Tri D. Setiyono, IRRI)
	5. Satellite Based Crop Monitoring & Estimation System for Food Security Application in Bangladesh (Mr Hafizur Rahman, SPARRSO, Bangladesh)
	Discussions
13.00–14.00	***Lunch Break***

14.00–16.00	**Session 3: Crop yield estimation using probability surveys and objective measurements**
	Chairperson: Ms Sarah Hoffman, USDA
	1. Rice Objective Yield Survey in Japan (Mr Masahiro Hosaka, Japan)
	2. Sampling Frame of Square Segment by Points for Rice Area Estimation (Mr Mubekti Munandar, Indonesia)
	3. Experience of Crop Cutting Experiments in Thailand (Ms Supaporn Bongsunun, Thailand)
	4. Recent Experiences of Sample Crop (rice) Cutting in Bangladesh (Mr Bidhan Baral, Bangladesh)
	5. The Agricultural Survey Improvement Program (Mr Mehrdad Nematzadeh Alidash, Iran)
	6. Promote the application of spatial information technology in crop production survey (Mr Ge WEI, the PRC)
	Discussions
16.00–16.15	***Coffee Break***
16.15–17.00	**Panel Discussion: Recommendation on choice of appropriate methodologies** (FAO, ADB, Representative from India, Philippines, Timor-Leste, and USA)
	The conclusion of this session will lead to a set of recommendations of suitability of methodologies in different situations, identification of current issues, best practices and directions for future research.
17.00 hrs.	**Closing session (FAO and ADB)**

Annex 3: List of participants

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Part II

Technical papers

Dot sampling method for area estimation

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Key words: Dot sampling Method, Attribute survey, Google Earth, Area survey, Preparatory survey, Field survey

ABSTRACT

The purpose of the paper is to introduce a new survey method for area estimation, what we call "the dot sampling method," and show an example of a rice planted area survey in developing countries by using this method. This new method has been developed by combining a traditional attribute survey method with two current information technologies, i.e., Excel and Google Earth. These combinations enable us to achieve a more simple, reliable, and cost-effective survey method in comparison with existing methods.

In Section 2 we illustrate how to estimate an actual planted area which is taken up for JICA training course. We show the procedure of the dot sampling method in detail, consisting of four steps: dot sampling, preparatory survey on Google Earth, field survey, and estimation of planted area by crop. This procedure can be easily applied to area survey at the country level.

By way of illustration we conducted a rice planted area survey in Sri Lanka and Thailand. In the paper, only the results of the preparatory survey on Google Earth are shown. Although the results obtained are found to be close to the official statistics in those countries, we believe that our results are statistically more objective than those obtained by using current methods, even official statistics.

1. Background

It is very important to develop a reliable and cost-effective survey method for the crop production surveys in the developing countries.

However, we recognize that it is difficult for developing countries to adopt area frame methods based on existing sampling methods because those methods incur high cost and require considerable labour, even in the preparatory stage of a sampling survey (it is necessary to construct area frames). Furthermore, those methods cannot solve the problems caused by non-sampling errors which often occur. In the process of developing the dot sampling method we learned a point sampling method which is used in European countries, but it seemed to be a complicated method because it requires both stratifications and two-stage sampling. We do not feel that the procedure itself is effective in any case. Moreover, it uses GIS. In general, such an expensive tool is not easy to learn. The latest remote sensing method incurs high costs and also requires both high techniques and considerable labour.

In contrast, the dot sampling method, which we are going to introduce here, is a new sampling survey method. It tries to estimate planted area by distributing sample dots systematically and directly to a whole target area on the Google Earth and then conducting a field survey at the sample dots in the target area. It does not require constructing area frames.

The dot sampling method is developed by combining a traditional statistical theory, which is called an attribute survey, with the latest information technologies, namely Excel and Google Earth. The method is simple, reliable, cost-effective and easy to learn. It took two years from 2011 to 2013 to develop this method.

The method also has resolved a lot of issues on crop surveys (e.g. how to construct master sampling frames, how to select survey items, i.e. not only core crops but also rare crops, how to measure dykes, slope, complicated fields, mixed cropping, how to avoid non-sampling errors, how to build human capacities, how to conduct trainings, how to reduce survey costs, etc.) which we had been facing for a long time.

We thank FAORAP for giving us a chance to explain the dot sampling method at the "Expert Meeting on Crop Monitoring for Improved Food Security" on 17 February 2014 held as a side event of 25th APCAS[1]. We are pleased to share the dot sampling method and our experience with you.

2. Methodology and procedure

2.1 Dot sampling method

The dot sampling method originates in the point sampling method which is a traditional sampling method, i.e. an attribute survey method. In the process of improving existing methods, we have developed a new method based on the latest information technologies (Excel and Google Earth on the Internet). Therefore we named it "dot sampling method." Dot sounds like a suitable word reflecting the Internet Age.

As mentioned above, the dot sampling method originates in the point sampling method. Dr Frank Yates describes the point sampling method as follows[2]:

> ***3.9 Sampling with probabilities proportional to size of units***
>
> *"If we have areas demarcated on a map, such as fields, and a point is located at random on the map, the probabilities of the point falling within the boundaries of the different fields are clearly proportional to the areas of the field. Consequently, areas can be selected at random with probabilities proportional to their size by the simple procedure of taking random points on the map."(P.35)*[3]
>
> *"The principle has applications in agricultural surveys designed to determine the acreage and yield of different crops, total cultivated area, etc. All that is required for acreage is to determine the proportion of points which fall in areas of the given type. The method is therefore particularly attractive when carrying out surveys of the area crops, etc. by aerial survey, provided the different crops can be recognized on the photograph, since it avoids all the measurement of area which would be required if an ordinary random sample of areas were taken."(P. 35)*
>
> ***4.24 Use of maps as frames in agricultural surveys***
>
> *"If accurate large-scale maps showing the field boundaries are available, the point method of sampling is very suitable for crop surveys in which contact with farmer is not necessary. The fields will then act as sampling units, and selection will be with probability proportional to size. Provided the whole of a selected field is under a single crop, all that is necessary for acreage estimates is to ascertain the crops, no determination of area being required. If more than one crop is being grown on a selected field, the proportions of area under the different crops must be determined, but eye estimate will usually be adequate for this purpose.*

[1] Concept Note "Expert Meeting on Crop Monitoring for Improved Food Security" 17 February 2014, Vientiane, Lao PDR.

[2] *Sampling methods for census and surveys* by Frank Yates, London, 1949.

[3] This is the most important concept in the "dot sampling method" for area surveys.

In this type of work two-stage sampling[4] will often be advisable in order to save traveling, and also to avoid having to handle an excessive number of maps". (P. 82)

The old traditional sampling method stimulated us to develop the new dot sampling method. The basic idea of the dot sampling method[5] is to simply use a "dot sheet"[6] for an area survey. It is easy to learn the dot sampling method using the dot sheet.

As you can see Figure 1 and Figure 2, the dot sheet has two types. Figure 1 shows a simple random dot sheet, and Figure 2 shows a systematic random dot sheet. The latter sheet is more popular and practical than the former one. The dot sheet has three functions:

1. "random sampling without sampling list"
2. "a share estimator without measuring"
3. "a special function to be square area frame for variable survey"[7].

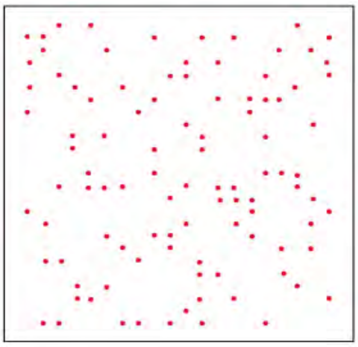

Figure 1. Simple random dot sheet

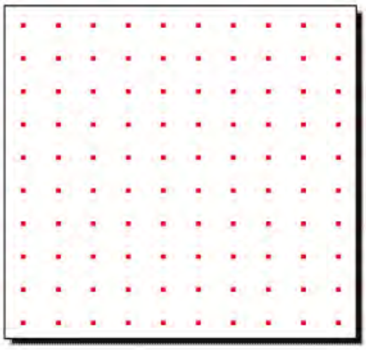

Figure 2. Systematic random dot sheet

Owing to the first function, you can select sample dots without a sampling list. It means that you don't have to construct sampling frames, which requires considerable work.

When you use this function for a sampling, you just overlay the dot sheet on the target area (Figure 3). The overlaying of the dot sheet on the area realizes the PPS sampling (probabilities proportional to size of fields [units]). Each sample dot selected with systematic random sampling is given the location by the dot sheet. This is the basic idea of dot sampling using the dot sheet. Each dot can be given a name automatically in actual surveys.

The second function suggests that you can conduct an area survey without measuring the area at sample fields[8]. This function is shown in Figure 4. Sample dots are already put within a target area.

[4] We adopt single stage sampling. The two-stage sampling method is not always effective.

[5] It was in May 2011 that the dot sampling method was suggested to us by Mr Kenji Kamikura who is a senior statistician in MAFF of Japan.

[6] We used the systematic dot sheet to measure the area of cultivated lands on maps not only when we were young officers but also when we were primary school children, but we did not have the idea of using it as a sampling tool or of using it as a tool to estimate the share of land use category in a large area. Of course, we had learned about attribute surveys, but we did not regard it as important.

[7] The third function will be explained later (See P. 11).

[8] Before we reached the dot sampling method, we had experienced using the list frame method and (both physical and mesh) the area frame method. We thought that area sampling surveys should be based on frames, and so it must be impossible to estimate reliable area without frames. But we knew those were not always efficient. After giving up using those authoritative methods, we have finally obtained a lot of useful results.

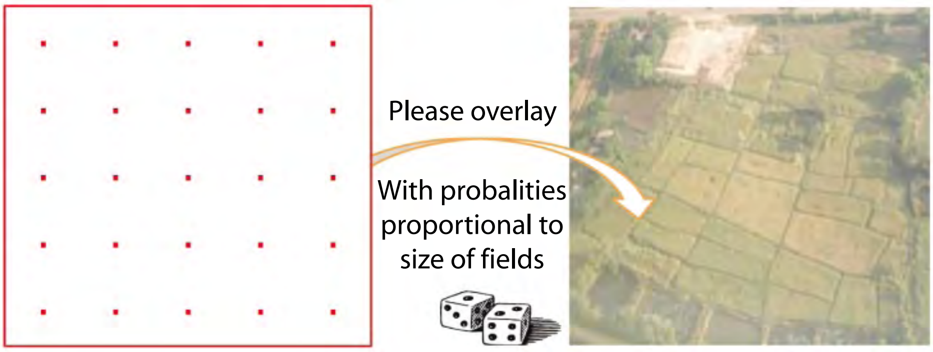

Figure 3. Dot sheet and target area

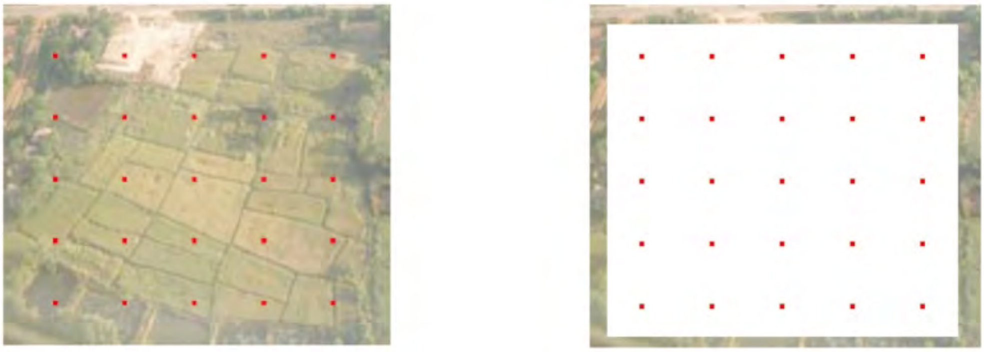

Figure 4. Dot sheet on the target area

When you conduct an area survey you identify the category of land use at the sample dots, and you count the number of dots by category to estimate the proportion[9]. Therefore, you don't have to measure. Such a survey method is called "attribute survey." Since there is no need to measure, you do not need close access to the sample field.

Furthermore, the number of survey items at a sample dot is only one item. It makes a questionnaire simple. It also makes the survey effective.

But, you can estimate land use areas by category based on a statistical formula, and calculate reliabilities, namely sampling error.

The formulas which are used are shown below:

Estimate: $\hat{T} = \frac{n_1}{n} W = \hat{p} W$

where,

W : Whole area of target area.

n : Number of sample dots

n_1 : Number of sample dots which are identified on the survey item (e.g. rice field)

Standard error (SE) $\mathrm{SE} = \sqrt{\hat{p}\hat{q}/n}$,

[9] Therefore, it is occasionally called "proportion estimator".

Coefficient of Variance of Standard Error (hereafter abbreviated as CV) is calculated as $\mathrm{SE}/\hat{p}$.

where

$\hat{p} = \frac{n_1}{n}$, $\hat{q} = (1 - \hat{p})$

Non sampling errors, such as measuring errors, hardly occur in this method. When you conduct a survey, you don't have to worry about whether a sample dot is composed of a complicated field, a mixed cropping field[10], or slope land, because it is an attribute survey. These merits are due to the properties included in the attribute survey.

2.2 Procedure of the Dot sampling method for a planted area survey

Based on the basic idea mentioned above, we designed the procedure of the dot sampling method for a planted area survey in Figure 5 below. It consists of four steps. The first step is "dot sampling"; the second step is "preparatory survey"; the third step is "field survey"; and the fourth step is "estimation". To realize the idea, especially in the first step, we developed two techniques using Excel VBA. One is to generate the systematic random sampling dots on an Excel sheet and the other is to put those sample dots on Google Earth.

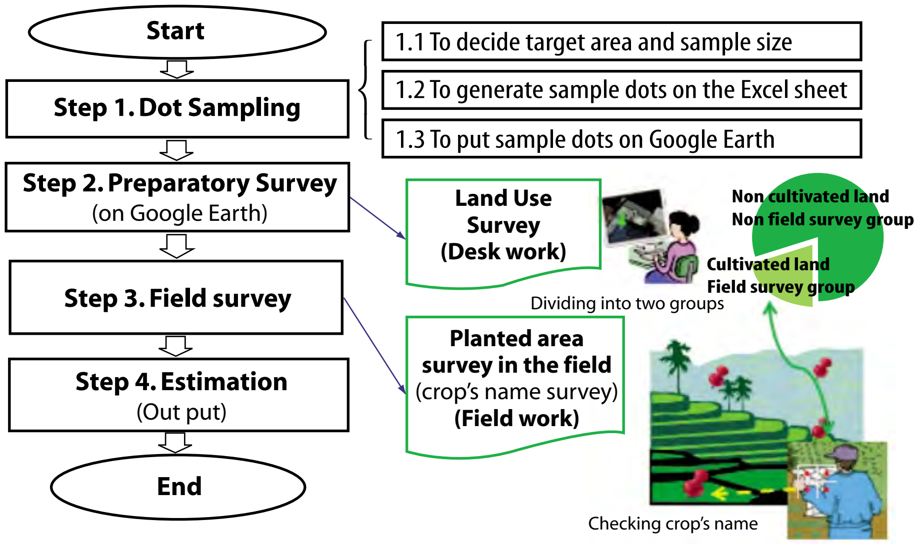

Figure 5. Procedure of the dot sampling method for a planted area survey

Next we explain how to apply the method to an actual planted area survey, step by step, choosing as a target area the area of the JICA training course in Tsukuba city in Japan.

The actual planted area survey method is lectured on in a JICA training course[11] every year. The area survey is conducted in a small area, but the procedure can be applied directly to an area survey in a large area, even at the country level.

[10] When you find mixed cropping at a sample dot, you have only to give "1" to each crop without considering the weight of planting crop's area. In that case, an increase in the planted area of each crop would come to decrease its yield.

[11] "Planning, designing and implementing of sampling survey (crop production survey), from Sep. 2 to Sep. 9 2-13" in the "PLANNING AND DESIGNING OF AGRICULTURAL STATISTICS FOR FOOD SECURITY MAKING" by JICA. From AUG. 25 to OCT. 19, 2013. The training course was held in November 2011, September 2012 and September 2013. There were 16 participants from 15 countries in Asia and Africa in 2013.

Step 1: dot sampling

The first step, i.e. the dot sampling, consists of three sub-steps. The first sub-step is to determine target area and sample size; the second sub-step is to generate sample dots on the Excel sheet; and the third sub-step is to put sample dots on Google Earth.

Step 1.1: To decide target area and sample size

The target area is shown in Figure 6. This area is located close to JICA's Tsukuba International Center. The size of target area is 24 ha (400 m x 600 m).[12]

Sample size is determined considering aimed precision, budget, manpower, etc. In the case of the JICA training courses in 2011, 2012 and 2013, the sample size was 96.

Figure 6. Target area around JICA Tsukuba International Center

Step 1.2: To generate sample dots on the Excel sheet

The sampling in a target area is conducted on the Excel sheet using our macro program[13].

First, as shown in Table 1 below, you input the data (Name of target area; Size of the target area; Sample size; Starting point; and Finishing point[14] with latitude and longitude) which are required in the T-1. Then, based on the inputted data, the Excel macro program automatically generates sample dots on the T-2.

The location of each sample dot is shown in combination with latitude and longitude. This is the sampling on the Excel sheet. Each sample dot is given a name by numbering rows and columns of the table, and those can be automatically converted on Google Earth (See Figure 7). This procedure makes it easy to check the category of land use at sample dots and to visit in the field.

Step 1.3: Putting sample dots on Google Earth

Based on the data of the Excel sheet which is shown above, the sample dots with names are displayed in the target area on Google Earth by a macro program[15] as seen Figure 7 below.

[12] In this case, the shape of the target area is a rectangle. It might be interesting to draw a figure which has complicated boundaries or physical boundaries.

[13] The program was made by Issei Jinguji.

[14] Starting point and Finishing point are shown in Figure 7.

[15] This program was developed by Mr Hakan Yuksel.

Table 1. Dot sampling table combining latitude and longitude

T-1 Basic data to generate sample dots (Sampling Design)

Target area	Size of the Target area km²	Sample size	Starting point (latitude)	Starting point (longitude)	Finishing point (latitude)	Finishing point (longitude)	Interval in km (depend on (3))	Necessary Number of Lines	Necessary Number of Rows
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)=√((2)/(3))	(9)	(10)
JICAshimoyokob	0.24	96	36.030751	140.12411	36.027596	140.13022	0.05	8	11

T-2 Sample dots (Coodinate Values) Don't change the numbers on yellow cells because the numbers are used for the calculations.

Name of Longitude → Latitude ↓	0	1	2	3	4	5	6	7	8
0,	36.03075098,140.1241082	36.03075098,140.124663606033	36.03075098,140.125219012066	36.03075098,140.125774418099	36.03075098,140.126329824132	36.03075098,140.126885230165	36.03075098,140.127440636198	36.03075098,140.127996042231	36.03075098,140.128551448264
1,	36.030300311329,140.1241082	36.030300311329, 140.124663602856	36.030300311329, 140.125219005711	36.030300311329, 140.125774408567	36.030300311329, 140.126329811422	36.030300311329, 140.126885214278	36.030300311329, 140.127440617133	36.030300311329, 140.127996019989	36.030300311329, 140.128551422844
2,	36.029849642658,140.1241082	36.029849642658, 140.124663599678	36.029849642658, 140.125218999356	36.029849642658, 140.125774399034	36.029849642658, 140.126329798712	36.029849642658, 140.12688519839	36.029849642658, 140.127440598068	36.029849642658, 140.127995997746	36.029849642658, 140.128551397424
3,	36.029398973987,140.1241082	36.029398973987, 140.124663596501	36.029398973987, 140.125218993001	36.029398973987, 140.125774389502	36.029398973987, 140.126329786003	36.029398973987, 140.126885182503	36.029398973987, 140.127440579004	36.029398973987, 140.127995975504	36.029398973987, 140.128551372005
4,	36.028948305316,140.1241082	36.028948305316, 140.124663593323	36.028948305316, 140.125218986647	36.028948305316, 140.12577437997	36.028948305316, 140.126329773293	36.028948305316, 140.126885166617	36.028948305316, 140.12744055994	36.028948305316, 140.127995953263	36.028948305316, 140.128551346586
5,	36.028497636645,140.1241082	36.028497636645, 140.124663590146	36.028497636645, 140.125218980292	36.028497636645, 140.125774370438	36.028497636645, 140.126329760584	36.028497636645, 140.12688515073	36.028497636645, 140.127440540876	36.028497636645, 140.127995931022	36.028497636645, 140.128551321168
6,	36.0280469679741, 140.1241082	36.0280469679741,140.124663586969	36.0280469679741,140.125218973938	36.0280469679741,140.125774360907	36.0280469679741,140.126329747875	36.0280469679741,140.126885134844	36.0280469679741,140.127440521813	36.0280469679741,140.127995908782	36.0280469679741,140.128551295751
7,	36.0275962993031, 140.1241082	36.0275962993031,140.124663583792	36.0275962993031,140.125218967583	36.0275962993031,140.125774351375	36.0275962993031,140.126329735167	36.0275962993031,140.126885118959	36.0275962993031,140.12744050275	36.0275962993031,140.127995886542	36.0275962993031,140.128551270334
8,	36.0271456306321, 140.1241082	36.0271456306321,140.124663580615	36.0271456306321,140.125218961229	36.0271456306321,140.125774341844	36.0271456306321,140.126329722459	36.0271456306321,140.126885103073	36.0271456306321,140.127440483688	36.0271456306321,140.127995864303	36.0271456306321,140.128551244917

Figure 7. Sample dots which are put in the target area on Google Earth

This technique makes a survey effective dramatically. Before the development of the macro program, we put sample dots one by one on Google Earth manually. Both Starting point and finishing point are required to generate the T-2 table.

Step 2: Preparatory survey for field survey on Google Earth

After the sampling, a "land use survey" is conducted on Google Earth, which is called the "preparatory survey" for the field survey. It is desk work. The main purpose of the survey is to make the field survey more efficient.

Table 2 shows the questionnaire for the preparatory survey, which has been filled in with the results of the survey. Category and codes are shown on the left side of the questionnaire.

You will find two rare or uncommon categories in Table 2. One is "Dyke", and the other is "Tentative reserve."

Table 2. Questionnaire of the preparatory survey (Sep. 2012)

	Category	Code
Cultivated land	Paddy field	1
	Dyke	2
	Upland	3
Non cultivated land	Residential land	4
	Road (asphalt)	5
	Road (soil)	6
	Irrigation, River	7
	Others	8
	Tentative reserve	9

	0	1	2	3	4	5	6	7	8	9	10	11
0	1	1	2	8	8	5	5	1	1	1	4	4
1	8	1	1	1	7	1	5	1	1	1	1	6
2	3	8	5	1	1	1	6	5	1	1	1	1
3	4	4	4	4	4	1	1	1	5	1	1	1
4	4	4	4	4	5	3	3	1	2	5	6	1
5	4	4	4	4	4	3	3	3	5	1	5	6
6	4	4	4	5	4	6	3	3	3	8	2	5
7	4	4	4	4	8	3	3	3	3	8	3	1

In general, cultivated land consists of two parts – one is field proper and the other is attached dyke. Dyke plays dual roles: one is as a field border and the other is to keep water in the rice field. In this table, "dyke" includes tree, rock, ant-hill, cottage, parking space, etc. Therefore, "Paddy field" and "Upland" do not include dykes here. These definitions are useful to estimate yield per unit (1 ha) based on the crop cutting survey, because crop cutting is conducted in the field proper which does not include dyke.

"Tentative reserve" makes your work efficient. For example, when you are conducting a preparatory survey, you may come across some sample dots whose land use categorization cannot be quickly determined. In such cases you can proceed to the next sample dots.

Through the preparatory survey, you can obtain information concerning the actual sample size of the field because you don't have to conduct field surveys at sample dots on the non-cultivated land. You should conduct field surveys at "Cultivated land" and "Tentative reserve"[16] individually.

Table 3 shows the results of the preparatory survey. These results are estimated from the preparatory survey on Google Earth. This table suggests that the role of the preparatory survey is not only to show the actual sample size of the field you should survey, but also to show land use statistics. It is thought that the results are close to real statistics, but have a little time lag. Furthermore, standard errors and CV are calculated by category.

These outputs show that you can obtain important information on land use statistics even in the stage of the preparatory survey[17].

Table 3. Results of the preparatory survey (Sep. 2012)

	Category	Code	Frequency	Share (%)	Area (ha)	SE	CV
Cultivated land	Paddy field	1	**30**	31.3	7.5	4.7	15.1
	Dyke	2	**3**	3.1	0.8	1.8	56.8
	Upland	3	**14**	14.6	3.5	3.6	24.7
Non cultivated land	Residential land	4	**24**	25.0	6.0	4.4	17.7
	Road (asphalt)	5	**12**	12.5	3.0	3.4	27.0
	Road (soil)	6	**5**	5.2	1.3	2.3	43.5
	Irrigation, River	7	**1**	1.0	0.3	1.0	99.5
	Others	8	**7**	7.3	1.8	2.7	36.4
	Tentative reserve	9	**0**	0.0	0.0	…	…
Total			**96**	100.0	24.0	0.0	0.0

[16] But, in this training, trainees visited all sample dots including "Non cultivated land". They could learn the method clearly by checking the category at each sample dot.

[17] Google Earth is what is called "Big Data". It has huge data, and we can use them for free. We can produce land use statistics from Google Earth.

Step 3: Field survey

When you conduct a field survey, Google Earth guides you to the sample dots on the map. You only identify the land use category of planted crops at sample dots.

The field survey should be conducted during the crop growing seasons. In the field survey, you don't have to survey at sample dots which are located on non-cultivated lands. As mentioned above, this is one reason why you should conduct a preparatory survey before the field survey. It makes the field survey more efficient. The actual sample size will be decreased dramatically (See P. 13-14).

Figure 8 shows that trainees are seeking a sample dot with guide maps. Behind them you can see rice fields.

Figure 8. Field survey with Google Earth maps (Sep. 2012)

Table 4 shows the questionnaire of the field survey. It is the same form as the preparatory survey. The category codes are shown at the left side. Yellow color (code 101) shows rice planted area. The results of the preparatory survey are updated by conducting the field survey. This relationship between the preparatory survey and field survey is very important in understanding the role of the field survey and the structure of the dot sampling method.

Table 4. Questionnaire of the field survey (Excel sheet) (Sep. 2012)

Category	Code
Dyke	3
Residential land, (Include building, parking, etc.)	4
Road (asphalt)	5
Road (soil)	6
Irrigation, River	7
Others	8
Paddy	101
Sweet potato	102
Soybean	103
Vegetable	104
Fruit (Tree)	105
Turf (Lawn)	106
No plant (prepalation)	107

	0	1	2	3	4	5	6	7	8	9	10	11
0	101	3	7	8	6	5	101	101	101	101	8	104
1	106	101	101	101	8	101	5	101	101	101	101	3
2	107	8	4	101	101	101	6	5	106	101	101	3
3	4	6	105	4	5	101	101	101	5	101	101	101
4	4	4	4	4	107	101	107	101	101	5	101	101
5	4	4	4	106	5	107	106	106	3	101	5	101
6	8	8	4	5	107	5	106	5	106	5	101	5
7	8	4	4	4	107	107	104	6	106	106	5	101

Step 4: Estimate of planted area by crop

Table 5 shows the results of estimates based on the field survey. You will find various crops which are growing at the sample dots. This means that you can estimate not only the core crops' planted area but also the rare crops' planted area. You can also calculate SE and CV by category. They are calculated using simple formulas, as we mentioned previously (See P. 4).

Table 5. Results of the planted area survey (Sep. 2012)

Category	Code	Number of dots	Share (%)	Area (ha)	SE	CV
Dyke	3	4	4.2	1.0	2.0	48.9
Residential land, (Include building, garden parking, etc.)	4	14	14.6	3.5	3.6	24.7
Road (asphalt)	5	14	14.6	3.5	3.6	24.7
Road (soil)	6	4	4.2	1.0	2.0	48.9
Irrigation, River	7	1	1.0	0.3	1.0	99.5
Others	8	7	7.3	1.8	2.7	36.4
Paddy	101	33	34.4	8.3	4.8	14.1
Sweet potato	102	0	0.0	0.0	0.0	…
Soybean	103	0	0.0	0.0	0.0	…
Vegetable	104	2	2.1	0.5	1.5	70.0
Fruit (Tree)	105	1	1.0	0.3	1.0	99.5
Turf (Lawn)	106	9	9.4	2.3	3.0	31.7
No plant (prepalation)	107	7	7.3	1.8	2.7	36.4
Total		96	100	24.0	0.0	0.0

3. Further discussions

This section introduces some interesting discussions and questions we have faced in the process of developing the dot sampling method. These issues have not been studied and arranged sufficiently yet, but will be interesting future research, especially for practical statisticians. Some of them might be difficult to solve, but we hope you will join us. We could discover something interesting such as the reliability of statistics, the relationship between the dot sampling method and other area frame survey methods, contrivances on the area survey, etc.

3.1 Random sampling and systematic sampling

It would be interesting to find out which is better – random sampling or systematic sampling (See P. 3, Figure 1, 2). Concerning this matter, Mr Nobunori Kuga, a senior statistician in the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan, conducted an experiment on the accuracy and precision of the dot sampling method using the Monte Carlo method to confirm the superiority in January 2014.The method and results are shown as follows.

First, please see Figure 9. This is an image graph; number of dots = 100. He drew a quarter circle in the square using *EViews* which is an application software on his PC. Next he put sample dots at random. The sample size is 10 000. Then he counted the number of sample dots which fell within a quarter circle, and calculated frequencies. The experiment was iterated 100 000 times. Then he summarized the results (Figure 10).

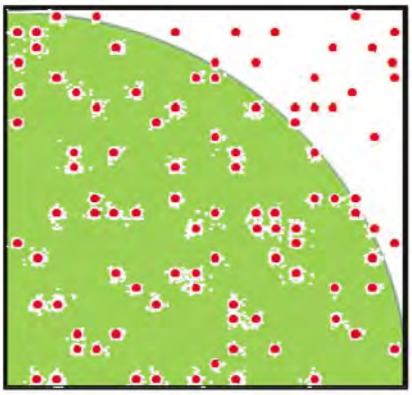

Figure 9. Image of the random sampling

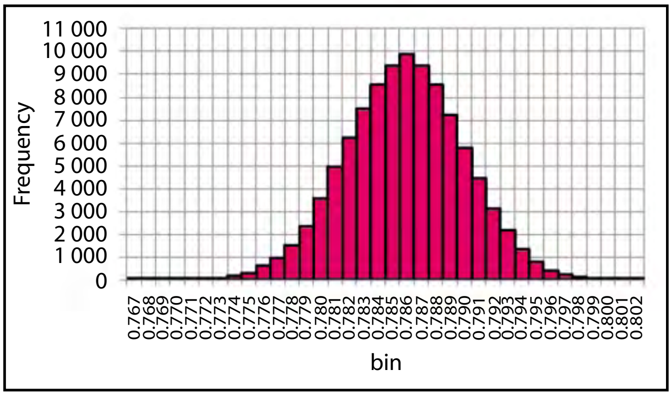

Figure 10. Frequency distribution of the random sampling

Next, in the same way as before, he tried the experiment on systematic sampling (See Figure 11). In case of systematic sampling, the first sample dot was put at the lower left corner (in the range of "0.01 x 0.01 = 1/10 000 square" including the origin) at random, and it was defined as the starting point; then the remaining sample dots (9 999 sample dots) are put in systematically. This experiment was also iterated 100 000 times (Figure 12).

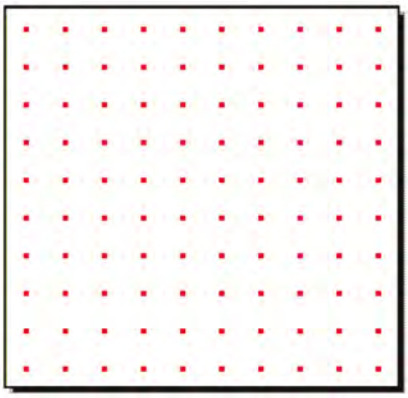

Figure 11. Image of the Systematic sampling

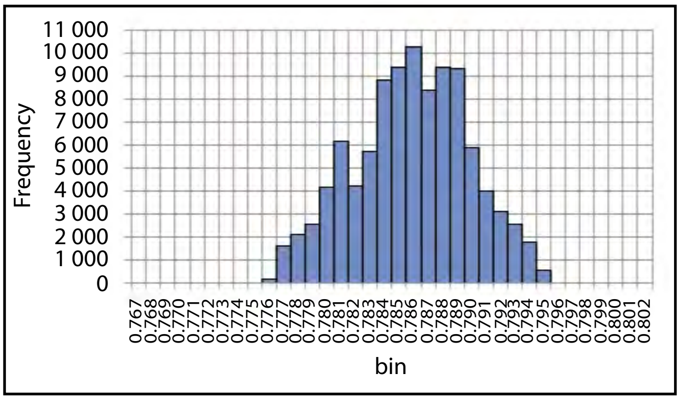

Figure 12. Frequency distribution of the systematic sampling

Finally, the comparison between the two experiments was shown in Table 6. The results of the experiments show that the shape of the frequency distribution of random sampling is more beautiful than that of systematic sampling. But, min, max and average of systematic sampling are better than those of random sampling respectively.

Table 6. Comparison of random and systematic

	Random	Systematic
Min	0.7669	0.7756
Max	0.8016	0.7949
Average	0.7853906	0.7854058
True value	0.7853982	0.7853982
Average/true value	0.9999904	1.0000097
SD	0.0041119	0.0039703

From the practical point of view, systematic sampling is better than random sampling. Therefore, we are convinced that it is reasonable to adopt the systematic sampling method for the dot sampling method.

[Note] *Concerning this matter, this simulation method is used to estimate the value of π. The theoretical share is shown as below.*

$$(True)\,Share\;P = \frac{A_{circle/4}}{A_{square}} = \frac{(\pi r^2/4)}{r^2} = \frac{\pi}{4} = \frac{3.1415926536\ldots}{4} = 0.785398163$$

The formula shows that circumference rate (π) can be estimated using the formula. $\hat{\pi} = 4\hat{p}$. *Therefore it suggests that you can estimate the value of π using sampling method. Please try it while changing sample size.*

3.2 A test survey on the dot sampling method in Kamakura city

A test survey on the land use was conducted in Kamakura (Area: 39.6 km^2) in Japan in December 2012 in order to determine the reliability of the dot sampling method in a small city. The test survey was conducted by using the third function to make square area frames with dots[18].

The idea of the test is basically the same as the Monte Carlo simulation mentioned above, although the scale is small. The outline of the test was as follows.

First, we selected a sample by using the dot sampling method with square frames (see Figure 13). The sample size was 994. The square frame was set such that the original sample dot should be the center of the square frame. The size of square frame is 50 m x 50 m[19]. The distance between each pair of sample dots is about 200 m.

Figure 13. Dot sampling with square area frame in Kamakura city

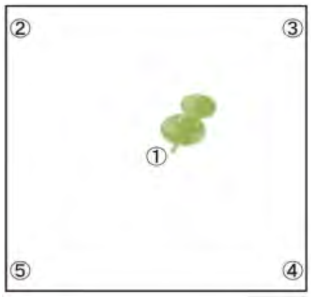

Figure 14. Original sample dot and square frame

Second, as shown in Figure 14, by using five sample groups of the center and the corners of the square frame, we conducted a preparatory survey at each dot[20] on Google Earth.

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[18] See P. 3. This function of the dot sampling method suggests that it can make square area frames for valuable survey. This function can be applied to the mesh area frame survey. The length of a side can be used for a transect frame. The transect frame is tried in the LUCAS method.

[19] The size of square is changeable.

[20] This function can be a cluster sampling method. LUCAS method in EU used the cluster sampling method.

Third, the results of the test were generated as follows:

Table 7. Number of sample dots by category/sampling group

	Sampling group					
	①	②	③	④	⑤	Total
Cultivated land	38	41	28	30	31	168
Wood	372	385	390	381	381	1 909
River, Lake, Beach	10	9	7	10	9	45
Residence, Park, etc.	488	468	498	491	478	2 423
Road	86	95	68	80	93	422
Total	994	998	991	992	992	4 967

Table 8. Share of sample dots by category/sampling group

	Sampling group					
	①	②	③	④	⑤	Average
Cultivated land	3.8	4.1	2.8	3.0	3.1	3.4
Wood	37.4	38.6	39.4	38.4	38.4	38.4
River, Lake, Beach	1.0	0.9	0.7	1.0	0.9	0.9
Residence Park, etc.	49.1	46.9	50.3	49.5	48.2	40.3
Road	8.7	9.5	6.9	8.1	9.4	8.5
Total	100	100	100	100	100	100

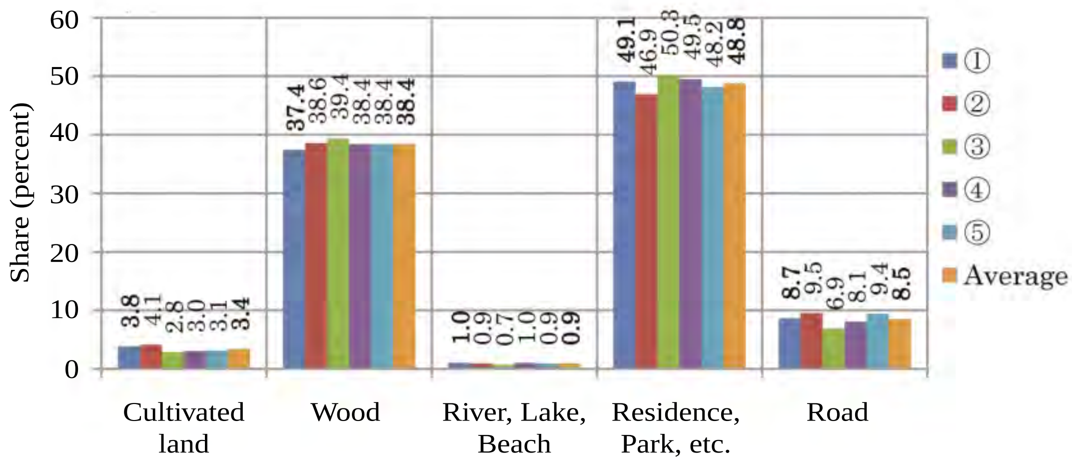

Figure 15. Comparison of estimate by category/sampling group

Table 7 shows the number of sample dots by category/sampling group. Table 8 shows the share of each group, and Figure 15 is drawn by using the data in Table 8.

As you can see, Figure15 shows that each estimate (① , ②, ③, ④ and ⑤)[21] is close to the "Average". "①" which belong to the original sample dot group is also close to each estimate. We think that according to the results, the estimate by the dot sampling method is reliable. Even the estimates of river, lake, and beach which has small shares is reliable too. But, the estimates are generated similarly in any case. It is thought that differences among the estimates occur due to "sampling error" caused by the different sample.

[21] As you can see, total number of sample dots are different from each other in Table 7. The reason why the sample size of each ②, ③, ④ and ⑤ are different from that of original sample ①, is because five dots do not always fall together within the boundary of Kamakura city.

If you want more reliable estimates, you need to increase the sample size. In addition, it is a good idea to fix sample dots over several years. If you avoid the sampling errors caused by a change to the sample every year, you will be able to find the tendency of the progress clearly.

3.3 Relations between share (%) of cultivated and CV by sample size

Figure 16 shows the relationship between the share of cultivated land and CV by sample size. The graph indicates the following:

- The best way to increase reliability is to increase sample size.
- The smaller the sample size and the share makes CV larger.
- The larger sample size makes CV smaller, whereas the larger share makes CV smaller.

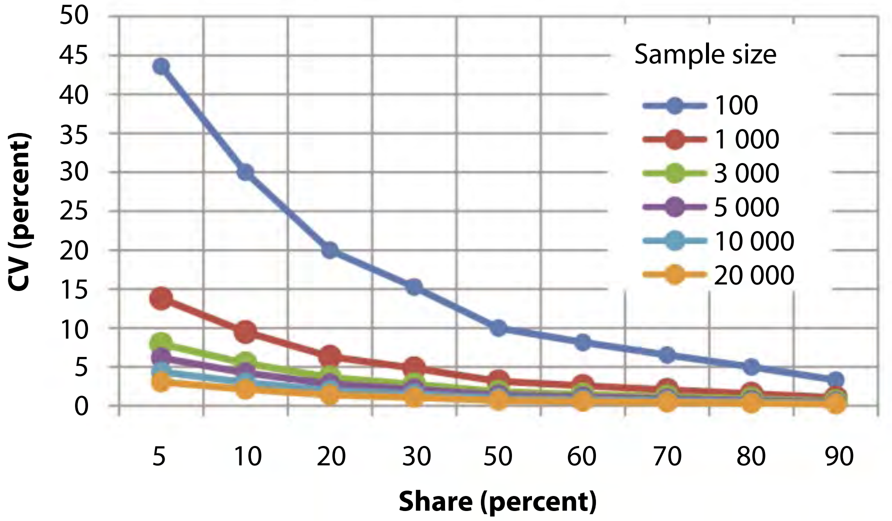

Figure 16. Relations between share (%) of cultivated and CV by sample size

When you conduct a planted area survey, you don't have to survey sample dots which are located at non-cultivated lands. The actual sample size of the target area you want to survey depends on the magnitude of the share of cultivated lands.

In addition, this graph is useful not only for the calculation of the sampling error after the survey, but also for designing the sample size. For example, when you design a sampling survey of rice planted area in your country based on this method, you may have existing data on the share of rice planted area calculated by the traditional method. If you determine the approximate share and your aimed CV, this graph could suggest the corresponding sample size. For example, when the share is 50 percent (30 percent), and aimed CV is 10 percent (5 percent) in your country, the necessary sample size (n) is 100 (900) approximately.

Concerning this matter, the next discussion will be useful.

3.4 Actual sample size for a field survey

As discussed above, the sample size of the preparatory survey is determined by considering precision, i.e. aimed, CV. On the other hand, you don't have to conduct field surveys at sample dots in non-cultivated land which are categorized in the stage of the preparatory survey. Therefore, the sample size of the field survey is definitely smaller than that of the preparatory survey.

If you make a plan to conduct a field survey in the whole area, you need much budget and manpower. If the purpose of the survey is to estimate planted area, the field survey should be conducted at the sample dots in the cultivated area.

Table 9 shows both the needed sample size and actual sample size determined by aimed CV, respectively.

As you can see, when cultivated land which is a target category has a share of 20 percent and your aimed CV is ±3 percent (5 percent), the needed sample size is 4 444 (1 600), whereas the sample size in the field survey is only 889 (320). You can see that the actual sample size is decreased. Therefore, please don't be afraid that the attribute survey requires a big sample size. A large part of sample dots can be surveyed at your desk in the preparatory stage.

Table 9. Needed sample size by CV and actual sample size by CV

Share of Cultivated Land (%)	Share of Non cultivated land (%)	Needed sample size by CV (%) (Preparatory survey			Actual sample size by CV (%) (Field survey)		
p	q = (100 – p)	3	5	10	3	5	10
1	99	110 000	39 600	9 900	1 100	396	99
2	98	54 444	19 600	4 900	1 089	392	98
3	97	35 926	12 933	3 233	1 078	388	97
4	96	26 667	9 600	2 400	1 067	384	96
5	95	21 111	7 600	1 900	1 056	380	95
10	90	10 000	3 600	900	1 000	360	90
15	85	6 296	2 267	567	944	340	85
20	80	4 444	1 600	400	889	320	80
30	70	2 593	933	233	778	280	70
40	60	1 667	600	150	667	240	60
50	50	1 111	400	100	556	200	50
60	40	741	267	67	444	160	40
70	30	476	171	43	333	120	30
80	20	278	100	25	222	80	20

3.5 Category for land use survey

If you make a plan for a land cover/use survey, how to determine the category for land use would be an important issue. The category table is prepared according to the purposes of the land use survey. Table 10 shows three kinds of category tables for land use survey.

Table 10. Category tables for land use survey

T1 Standard

Category	Code
Crop land	a
Forest land	b
Grassland	c
Wetland	d
Settlements	e
Otherland	f
Water	g

T2 Preparatory survey for crop survey

Category Name	Code
Non-cultivated land	1
Cultivated land (Upland)	2
Dyke (Upland)	3
Lowland (paddy)	4
Lowland (Dyke)	5
Tentative	8
Low resolution	9

T3 Field survey

Category	Code
Rice (lowland)	11
Rice (upland)	12
Cassava	13
Meize	14
Soybean	15
Sugarcane	16
Vegetable	17
…	…

T1 is a standard classification. This is suggested by the World Bank and FAO[22]. T2 is a special category which is used in our preparatory survey for the crop production survey. In the T2 table, "Dyke" is added for the special purpose of estimating real planted area. "Tentative reserve" plays a special role in making preparatory survey efficient. T3 is a category table for a field survey. It is used when you estimate planted area by crop[23]. The target crops are determined by the designer of the survey. You can put here all the codes of crops which you want to estimate.

4. Results obtained: Application of the method at the country level

So far we have explained the dot sampling method and how to use it concretely for some specific small area, which is taken up in the JICA training course activities. In this section, we would like to introduce the results obtained by applying the method at the country level. The procedure necessary to implement the method for a large area is the same as that for a small area, although the field surveys have not been conducted yet.

4.1 Sri Lanka

First, we would like to discuss the case of Sri Lanka, where we conducted a land use survey using the dot sampling method in December 2013. As you can see, Table 11 shows the dot sampling on an Excel sheet. Figure 17 shows sample dots which are put on Google Earth. The sample size is only 100. This sample size is determined tentatively as an example. Based on the theory of probability, the number of sample dots which fall within the border of Sri Lanka is determined as the actual sample size. Therefore, the designed 100 sample dots do not always fall exactly within the border, but the error is small, ±1 or ±2 from our experience. Those are the results of the first step.

Table 11. Dot sampling table on Excel sheet (Sri Lanka)

1. Fill in blank cell on T-1 Table below

T-1 Basic data to generate sample dots (Sampling Design)

Target area	Size of the Target area km²	Sample size	Starting point (latitude)	Starting point (longitude)	Finishing point (latitude)	Finishing point (longitude)	Interval in km (depend on (3))	Necessary Number of Lines	Necessary Number of Rows	Index of Line on the work sheet
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)=√((2)/(3))	(9)	(10)	(11)
Sri Lanka100	*65,610,000*	*100*	*9.885*	*79.385*	*5.886*	*82.098*	25.614449	18	12	34

T-2 Sample dots (Coodinate Values) Don't change the numbers on yellow cells because the numbers are used for the calculations.

Name of Longitude → Latitude ↓	0	1	2	3	4	5	6	7	8	9
0,	9.885,79.385	9.885,79.61856596 0175	9.885,79.85213192 03499	9.885,80.08569788 05249	9.885,80.31926384 06999	9.885,80.55282980 08748	9.885,80.78639576 10498	9.885,81.01996172 12248	9.885,81.25352768 13998	9.885,81.48709364 15747
1,	9.65412740579358, 79.385	9.65412740579358 ,79.618403965971 5	9.65412740579358 ,79.851807931943	9.65412740579358 ,80.085211897914 5	9.65412740579358 ,80.318615863886	9.65412740579358 ,80.552019829857 5	9.65412740579358 ,80.785423795829	9.65412740579358 ,81.018827761800 5	9.65412740579358 ,81.252231727772	9.65412740579358 ,81.485635693743 5
2,	9.42325481158716, 79.385	9.42325481158716 ,79.618245980850 9	9.42325481158716 ,79.851491961701 8	9.42325481158716 ,80.084737942552 7	9.42325481158716 ,80.317983923403 7	9.42325481158716 ,80.551229904254 6	9.42325481158716 ,80.784475885105 5	9.42325481158716 ,81.017721865956 4	9.42325481158716 ,81.250967846807 3	9.42325481158716 ,81.484213827658 2
3,	9.19238221738074, 79.385	9.19238221738074 ,79.618091991552 5	9.19238221738074 ,79.851183983105	9.19238221738074 ,80.084275974657 5	9.19238221738074 ,80.31736796621	9.19238221738074 ,80.550459957762 5	9.19238221738074 ,80.783551949315	9.19238221738074 ,81.016643940867 5	9.19238221738074 ,81.24973593242	9.19238221738074 ,81.482827923972 5
4,	8.96150962317432, 79.385	8.96150962317432 ,79.617941985171 5	8.96150962317432 ,79.850883970343 1	8.96150962317432 ,80.083825955514 6	8.96150962317432 ,80.316767940686 1	8.96150962317432 ,80.549709925857 7	8.96150962317432 ,80.782651911029 2	8.96150962317432 ,81.015593896200 8	8.96150962317432 ,81.248535881372 3	8.96150962317432 ,81.481477866543 8
5,	8.73063702896791, 79.385	8.73063702896791 ,79.617795949156 7	8.73063702896791 ,79.850591898313 3	8.73063702896791 ,80.08338784747	8.73063702896791 ,80.316183796626 7	8.73063702896791 ,80.548979745783 3	8.73063702896791 ,80.78177569494	8.73063702896791 ,81.014571644096 7	8.73063702896791 ,81.247367593253 3	8.73063702896791 ,81.48016354241
6,	8.49976443476149, 79.385	8.49976443476149 ,79.617653871307 3	8.49976443476149 ,79.850307742614 5	8.49976443476149 ,80.082961613921 8	8.49976443476149 ,80.315615485229	8.49976443476149 ,80.548269356536 3	8.49976443476149 ,80.780923227843 6	8.49976443476149 ,81.013577099150 8	8.49976443476149 ,81.246230970458 1	8.49976443476149 ,81.478884841765 3
7,	8.26889184055507, 79.385	8.26889184055507 ,79.617515739770 9	8.26889184055507 ,79.850031479541 8	8.26889184055507 ,80.082547219312 7	8.26889184055507 ,80.315062959083 6	8.26889184055507 ,80.547578698854 6	8.26889184055507 ,80.780094438625 5	8.26889184055507 ,81.012610178396 4	8.26889184055507 ,81.245125918167 3	8.26889184055507 ,81.477641657938 2
8,	8.03801924634865, 79.385	8.03801924634865 ,79.617381543041	8.03801924634865 ,79.849763086082	8.03801924634865 ,80.082144629123	8.03801924634865 ,80.314526172164	8.03801924634865 ,80.546907715204 9	8.03801924634865 ,80.779289258245 9	8.03801924634865 ,81.011670801286 9	8.03801924634865 ,81.244052344327 9	8.03801924634865 ,81.476433887368 9

[22] FAO, The World Bank. (2010) *Global strategy to improve agricultural and rural statistics 15*

[23] The results of the planted area survey can be used for the crop cutting surveys. These sample dots are selected with PPS, so you can use those sample dots directly for the yield survey.

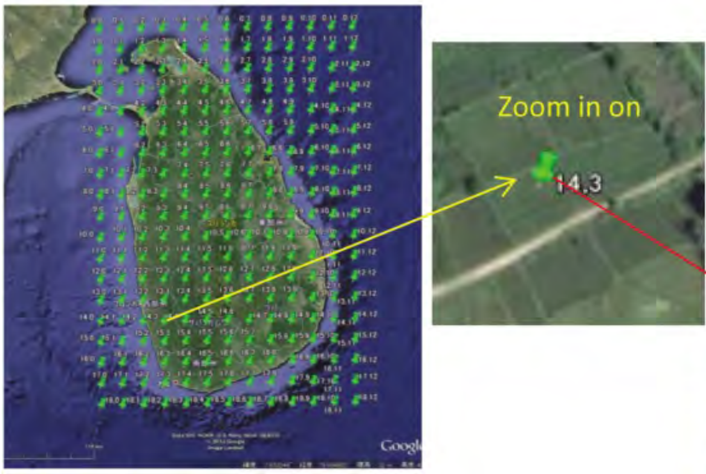

Figure 17. Sample dots on Google Earth

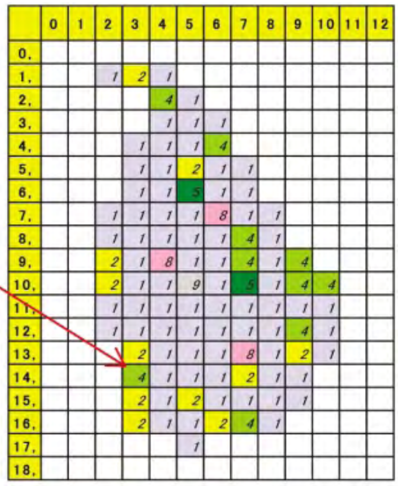

Figure 18. Questionnaire for preparatory survey

Figure 18 shows the results of the preparatory survey on Google Earth in Sri Lanka, and land use (whose codes are shown in Table 12) at each sample dot is categorized one by one. Table 12 shows the land use statistics obtained by the preparatory survey. Figure 19 shows the pie graph of Table 12. In addition, Figure 20 shows the comparison of the official statistics of harvested area and the dot sampling estimate of the paddy field. According to the graph, the estimate of paddy field is close to the official statistics. Although this is only a demonstration to learn the dot sampling method at the country level, our results are surprisingly close to the official statistics. Those are the outputs of the second step.

Table 12. Land Use Statistics

Category Name	Code	Number of Sample	Rate	SE	CV	Estimate (1 000 ha)
Non-cultivated land	1	73	0.73	0.04	6.1	4 790
Cultivated land (upland)	2	11	0.11	0.03	28.4	722
Dyke (upland)	3	0	0.00	0.00		0
Lowland (paddy)	4	10	0.10	0.03	30.0	656
Lowland (dyke)	5	2	0.02	0.01	70.0	131
Tentative	8	3	0.03	0.02	56.9	197
Low resolution	9	1	0.01	0.01	99.5	66
Total		100	1.00	0.00	0.0	6 561

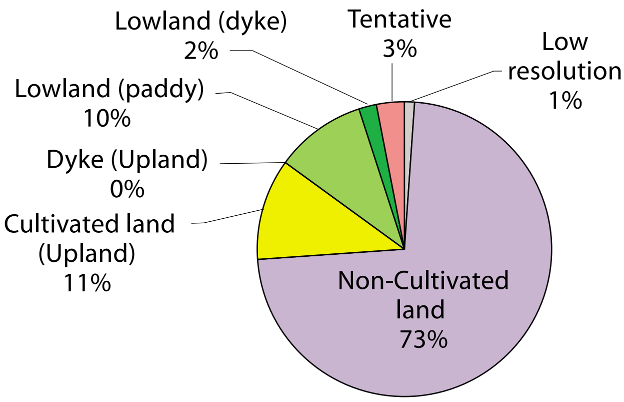

Figure 19. Land use in Sri Lanka

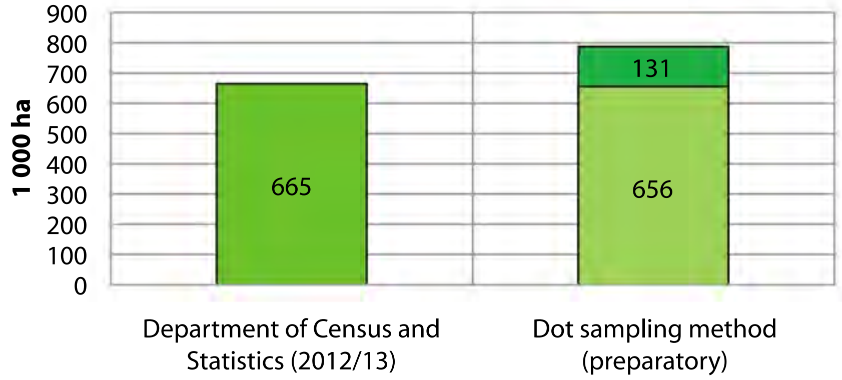

Figure 20. Comparison (Harvested area/Lowland)

As mentioned above, the purpose of this paper is to show the procedure of the dot sampling method. If you conduct the survey according to the procedure, you can quickly obtain the results of a land use survey on Google Earth like this. It took only one hour from beginning to end, partly because the sample size was only 100.

But, if you want to estimate the crops planted area in as actual crop growing season, you should visit sample dots which are put on cultivated lands (at least, upland + lowland + Dyke + Tentative[24]) in the crop growing season. In the above case, the number of sample dots you should visit is only 26, and you can estimate not only crop planted area, but also the share of dyke objectively.

An actual planted area survey is conducted like this. But we would like to suggest that you can estimate approximately the area of rice growing even using the preparatory survey on the Internet. You can also check the area of rice fields, including the share of dyke area, in Asian countries quickly.

4.2 Thailand

Next, we would like to show you land use statistics in Thailand, which were obtained from the preparatory survey. We conducted a test survey in August 2013; however, the field survey has not been conducted yet.

As you can see, those outputs show that even if the outputs are obtained from the preparatory surveys on Google Earth, the results/analysis might be useful. The sample size was only 1 000. The actual sample size was 999. It implies that all the sample dots fell within the border of Thailand. The difference might occur due to either probability or boundary lines on Google Earth.

Figure 21 shows a land use map in Thailand. Table 13 shows the results of the preparatory survey in Thailand. Figure 22 shows the comparison of the official statistics (Major rice) and the estimates by the dot sampling method (planted area + dyke). Both the values are close to each other. The data shows that official statistics on the planted area of major rice in Thailand are reliable. It is said, however, that the planted area includes dykes in Thailand. The share of dyke by the dot sampling method is 14.4 percent. We think it is a reasonable estimate.

[24] Tentative: Category to reserve deciding sample dot's category on the operation of the preparatory survey on a tentative basis. It is one of the measurements to go along smoothly.

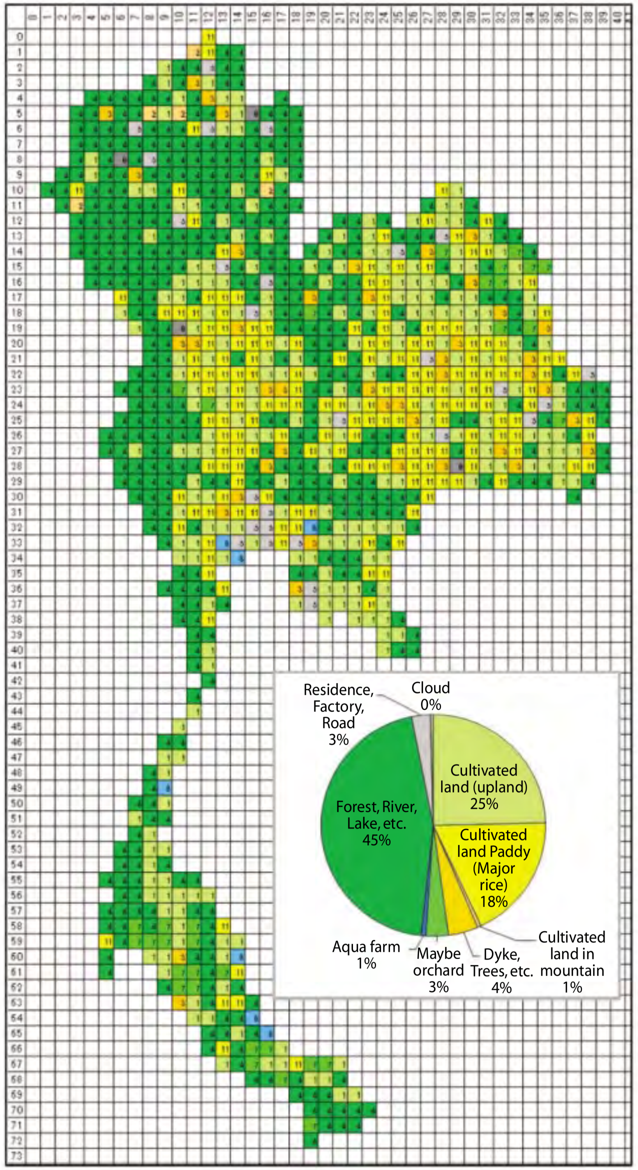

Figure 21. Land use map

Table 13. Land use statistics

Category		Code	Number of dots	Rate (%)	Area (ha)	SE	CV
Cultivated land		…	517	51.8	26 554 859	1.581	3.1
Cultivated land/ Breakdown	Cultivated land (upland)	1	246	24.6	12 635 387	1.363	5.5
	Cultivated land Paddy (Major rice)	11	184	18.4	9 450 859	1.226	6.7
	Cultivated land in mountain	2	5	0.5	256 817	0.223	44.6
	Dyke, Trees, etc.	3	43	4.3	2 208 625	0.642	14.9
	Maybe orchard	7	32	3.2	1 643 628	0.557	17.4
	Aqua farm	8	7	0.7	359 544	0.264	37.7
Forest, River, Lake, etc.		4	451	45.1	23 164 877	1.574	3.5
Residence, Factory, Road		5	27	2.7	1 386 811	0.513	19.0
Cloud		6	4	0.4	205 453	0.2	49.9
Total			999	100.0	51 312 000	…	…

Category		Number of dots	Rate (%)	Area (ha)	SE	CV
Paddy field	Pure planted area (Major rice)	184	18.4	9 450 859	1.2	6.7
	Dyke, Trees	31	3.1	1 592 264	0.5	17.7
	Total	215	21.5	11 043 123	1.3	6.0

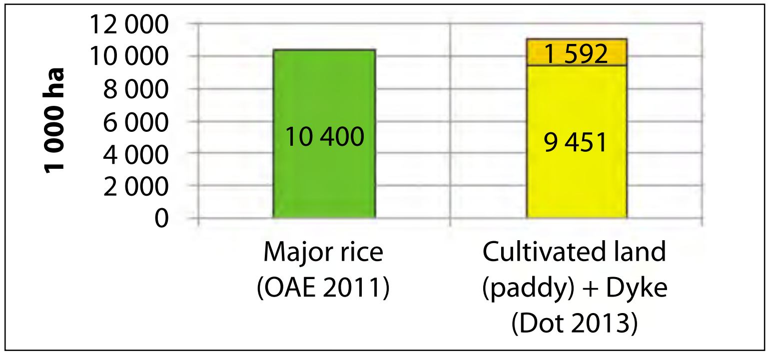

Figure 22. Comparison of the official and dot

[Note] *Concerning the matter of the dyke, how to handle dykes in a yield survey and area survey is a significant issue, since the definitions are usually unclear. In the case of Thailand, it is said that the dyke is included in the planted area. Therefore, although the yield is estimated by using the crop cutting method, the original crop cutting yield is adjusted to the official yield which includes dykes.*

In any event, when the production is calculated on the basis of "yield multiplied by area", yield must be defined including dyke, in case the area includes dyke, but in many cases in many countries there are no definitions on how to handle this issue[25]*. The dot sampling method is useful to estimate the area of dykes and the pure (proper) planted area. Please don't forget that this dot sampling method can be applied to the sampling for crop cutting surveys without making a list.*

5. Conclusion

So far we have explained what the dot sampling method is and how to use it. This method has been developed by combining the traditional attribute survey method with Excel and Google Earth, and we are still in the process of improving the method.

As mentioned earlier, the dot sampling method is quite simple and reliable. It has also succeeded in resolving various issues, which had been unresolved until now. Best of all, it can produce a lot of results in a short time. In fact, these advantages of the dot sampling method originate in the traditional attribute survey method. In our research process, we realized that combining this method with Excel and Google Earth enables us to make the most of the merits which are included in the attribute survey method.

Table 14. Advantages and achieved techniques

Items		Advantages/Achieved techniques
Attribute method Excel Google Earth		Simple statistical methodology No measuring (category survey) Non sampling errors hardly occur
		Sampling without list
		Accurate Web maps. (Location, Category)
Procedure	Sampling	on Excel Sheet, Google Earth.
	Preparatory	on Google Earth. Survey item: One (category)
	Field survey	on the Field. No contact with farmers. Resolved complicated land, rare crops, etc.
Results (Estimates)		Simple Manual/Questionnaire. Speedy, reliable outputs.

Simple
Easy
Reliable
Cost effective

The dot sampling method is a newly-born method. Unfortunately, it is not well-known. Its application at the country level has not been conducted yet. We hope that the method will be tested and used, especially in some Asia and the Pacific countries, in the near future.

6. Success achieved and issues for further research

As mentioned above, the dot sampling method can resolve a lot of issues, which have remained unresolved so far, e.g. simplicity, efficiency, reliability, etc. At this stage, we do not find any issues necessary for further research from the technical point of view.

[25] Kenji Kamikura. Senior Statistician, Statistics Department Ministry of Agriculture, Forestry and Fisheries of Japan (AfricaRice, Cotonue, Benein, March 2013). *Package of Agricultural Production Survey.*

However, we recognize that it is very difficult to use this method in developing countries. There are two main reasons. Firstly, the infrastructure for the Internet is vital. As mentioned repeatedly, we owe the dot sampling method mostly to Google Earth. Therefore, it is most important to improve the infrastructure for the Internet in order to use Google Earth. Second, it is very difficult for some governments to shift from traditional survey methods to a new survey method, e.g. the dot sampling method. It seems that nothing is more important than maintaining the status quo, e.g. the reporting method, which is based on the reports from the village or prefecture level.

Accordingly, the first step that we might recommend is that the government should use the dot sampling method to support the reporting method, or to check the results obtained with the reporting method. The method, especially the preparatory survey on Google Earth necessary in order to estimate cultivated land area, does not need to cost so much. There is no risk of losing a lot of money through this method.

It might also be a good idea to continue further research on crop survey methods, not only from the methodological and technical point of view but also from the sociological point of view.

Some countries in Africa are now conducting pilot surveys using the dot sampling method[26]. We expect that they will show good results and make suggestions for further research.

7. Acknowledgements

It is great pleasure to be invited to the Expert meeting in Vientiane in Lao PDR by FAORAP and to be given an opportunity to present and discuss the issue on the area survey method with participants.

Having this opportunity, we deeply appreciate experts'[26] cooperation in MAFF of Japan, JICA, MOAFC of Tanzania, Africa Rice Center and FAO who helped us to establish and disseminate the method.

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Agricultural Land Information System (ALIS) to support area sample survey

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ABSTRACT

Chronic lack of qualified manpower and budget constraints are the main factors for absence of sample surveys based on framework. The AFFIS project with a personal computer (PC) based tool to build area framework for estimation of agricultural land area has been created. The tool is called ALIS which also involves field survey to check the ground realities. Lao PDR and the Kingdom of Cambodia were selected for implementation of this project. This paper describes this technique which allows for the collection of reliable data on a low budget with limited manpower, and is therefore sustainable.

1. ASEAN Food Security Information System (AFSIS)

At the 1st Meeting of ASEAN Ministers on Agriculture and Forestry Plus Three (AMAF + 3), held 5 October 2001 in Medan, Indonesia, the Ministers approved the ASEAN Food Security Information System Project, which commenced in 2003. Since its commencement, the ASEAN Food Security Information System Project (hereafter referred to AFSIS) has been implemented by ASEAN, Japan with participation open to the People's Republic of China and the Republic of Korea to compile and synergize agricultural statistics and information in the region.

The main activities of the AFSIS Project are concerned with the construction of an information network system and human resource development. The AFSIS Project is currently providing food security-related information gathered from member countries to the public through its own created database and website.

2. Improvement of accuracy on statistics in country level

There was an issue on the fundamental differences of reliability on statistical data among member countries. It was necessary to meet the requirements of data users who want to grasp the regional situation.

In this regard, the AFSIS Project has tackled the above issues with member countries from 2011 through an improvement of the capacity of the countries on the accuracy of statistical data for further development of the database in collaboration with the Expert of the ASEAN Food Security Information System (hereafter referred to "AFSIS Expert") to whom the project task is assigned.

3. Consideration for improvement of data accuracy

Although it obviously appears that there are several methods for improvement of data accuracy, for instance the holding of seminars and training or improvement of the survey manual, survey definitions, etc. However, the AFSIS Expert has targeted the improvement of core statistics in the particular area of target countries. It was expected to have an impact on the improvement of data accuracy of the whole productive statistics by improvement of area data accuracy and enable the capacity building of sample surveys and statistical theory for staffs of target countries by conducting area sample surveys.

In addition, it was necessary to consider that the main factors hindering the conducting of sample surveys are the chronic lack of labour and budget on statistics work and shortage of staff experience.

Hence, the AFSIS Expert has developed a tool by using a personal computer (PC) to estimate agricultural land area and developed a statistical system to conduct area sampling with a small number of labour and low budget.

4. Logic for area estimation using PC

In principle, we can estimate the statistical data by using the following estimation formula:

$$Y = \frac{\sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} y_i} y$$

The notation used to describe this formula appears below (in case of area estimation):
Y = Estimated area of this year
y = Total area of last year
x_i = Area in "i" number sample of this year
y_i = Area in "i" number sample of last year
n = Number of survey sample

If we can obtain data that can match the above signs of concept and area framework of "n", we could possibly estimate "Y" easily by using this formula. However, in reality, the undeveloped area surveys of some countries cannot obtain any data aside from a doubtful "y".

On the other hand, we can seek the possibility of replacing the sign concept by using a PC for "Y". If we can make the area framework (N), select the indicated sample (n) randomly and calculate the area of sample (y_i) on the PC, we could estimate a tentative agricultural land area (y) as replacement for the area of last year. In fact, we can approach "Y" by using the below formulas:

$$Y = \frac{\sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} y_i} y \quad \text{at that time} \quad y = \frac{\sum_{i=1}^{n} y_i}{n} N$$

The notation used to describe this formula appears below (in case of the above approach):
Y = Estimated area of this year
x_i = Area in "i" number sample of this year
y = Tentative Agricultural land area made on the PC
N = Number of framework population made on the PC
y_i = Agricultural land area made on the PC in "i" number sample
n = Number of sample selected by PC
Remarks: only remains x_i as unknown data in this formula.

5. Development of Agricultural Land Information System (ALIS)

ALIS stands for Agricultural Land Information System. ALIS has been developed to accomplish the above replacement, in particular to create the area framework, to select the indicated sample randomly, and to calculate the area of sample on the PC.

In addition, ALIS is designed as a total supporting system for area sample survey by attaching the supporting functions of field survey, database function, etc.

The outline of ALIS functions are given below; however, the details of functions and operations are shown in the *ALIS Program Operation Manual*.

5.1 The function for the development of agricultural land mesh framework

ALIS can make area mesh frameworks out of picture-maps. For this purpose, ALIS has the following functions:

5.1.1 To scan picture-map

ALIS scans a target province picture-map out of Google Map. The province border line on ALIS is drawn based on Google information, which may have an accuracy problem. Therefore, ALIS has the map border registration function to modify it correctly in case of false border lines.

5.1.2 To make area mesh

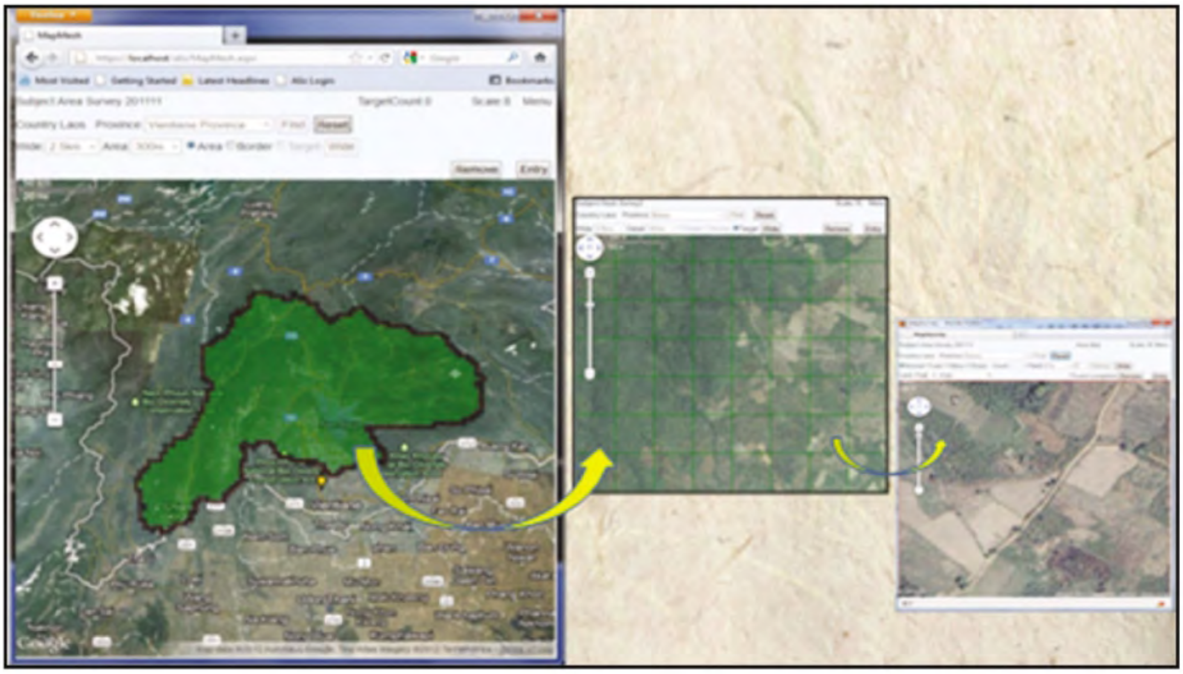

Figure 1. ALIS function for make area mesh

Figure 1 shows the actual operation screen of ALIS of Vientiane province in Lao PDR. ALIS makes an area mesh framework by indicated provinces, which means that ALIS estimates the area by province. ALIS has a function to make four kinds of mesh: 5 km mesh and 2.5 km mesh as wide mesh and 600 m mesh and 300 m mesh as area mesh. The Operator can make area mesh by selecting target province and mesh size and hold down the "Entry" button on the screen. A total of 121 152 area meshes of 300 m are registered in ALIS by this operation.

5.1.3 To add a mesh location information (latitude, longitude) and a mesh ID to each mesh

To add the ID to each mesh becomes an important operation in order to change from just a mesh aggregate to a statistical framework. ALIS adds mesh ID to each wide mesh and area mesh from top left to bottom right in series, for example 415-27 by province. These mesh IDs are displayed on the monitor during the operation and it is possible to search a mesh by inputting the mesh ID.

5.1.4 To create the sample framework

ALIS doesn't assume all area meshes made on Google Map as the sample framework but assumes area meshes, including cultivated land, of those as the sample framework. The sample framework should be treated as a class of "measurements" and not a factor to measure. For this purpose, ALIS operates the visible judgment on the Google Map screen, divides into "area meshes including cultivated land" and "area meshes not including cultivated land" and registers "area meshes including cultivated land" to the system as the sample framework.

On the other hand, the unified criteria for judgment area with visible judgment are essential for making the sample framework. The rules of making the sample framework in ALIS are shown in a study report *Consideration for making of area framework in ALIS* written by the AFSIS Expert.

5.1.5 To build the mesh database

ALIS saves the position information (latitude and longitude) of corners of the area mesh, agricultural land area data and crop planted area data by sampling based on mesh ID to the database. ALIS also makes a Mesh list sheet, Agricultural land area data sheet and crop planted area sheet by using the CSV file.

In addition, ALIS saves the borderline information of agricultural land area on each area mesh. This means ALIS is capable to reflect the borderline information to updated Google Map pictures.

5.2 The function for area calculation

ALIS can calculate the agricultural land area by tracing its border line on the PC monitor. For this purpose, ALIS has the following functions:

5.2.1 To classify agricultural land and planted crops land (rice, soybean, mais, sugarcane, cassava) by land indications

5.2.2 To calculate area by the land indication

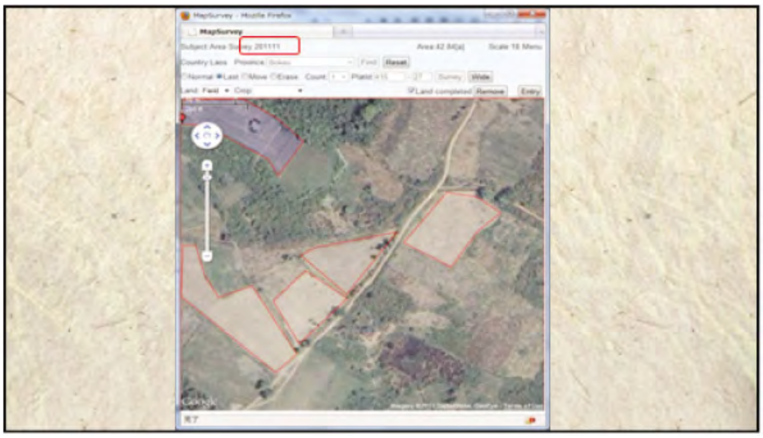

Figure 2. ALIS function for area calculation

We need to attach the mother population information to the mesh to make a statistical framework. In this case, we need to attach the area information to mesh. Figure 2 shows how ALIS calculates the agricultural land area by tracing its borderline on the PC monitor. The calculated area is displayed on the monitor with registration to database.

5.3 The function for survey support

ALIS can support the field area survey based on the sample method. For this purpose, ALIS has the following functions:

5.3.1 To conduct mesh sampling randomly

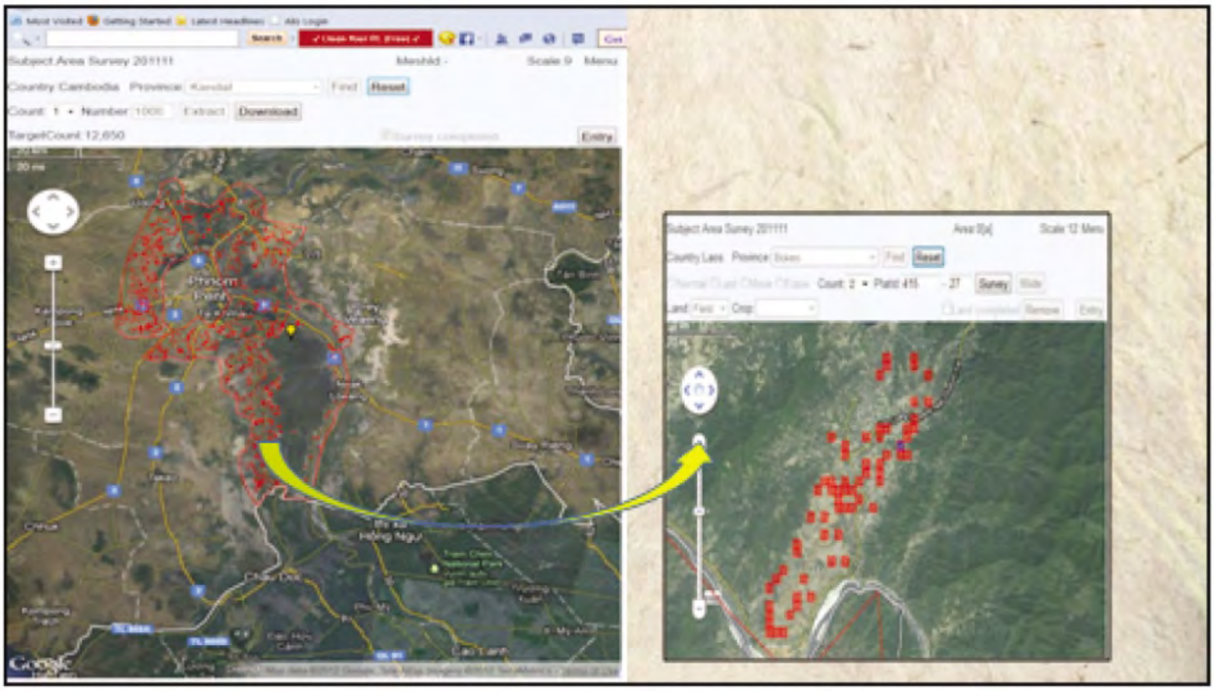

Figure 3. ALIS function for mesh sampling

Figure 3 shows the actual operation screen of ALIS in Kandal province in Cambodia. ALIS can extract the indicated number of sample mesh randomly for the purpose of sample survey.

5.3.2 To make wide map for guidance and survey sheet for researcher

ALIS makes a wide map and survey sheet of the indicated sample mesh, or in other words, for making "xi" remain as unknown data on estimation formula.

5.3.3 To estimate area using estimation formula and to compile result sheet

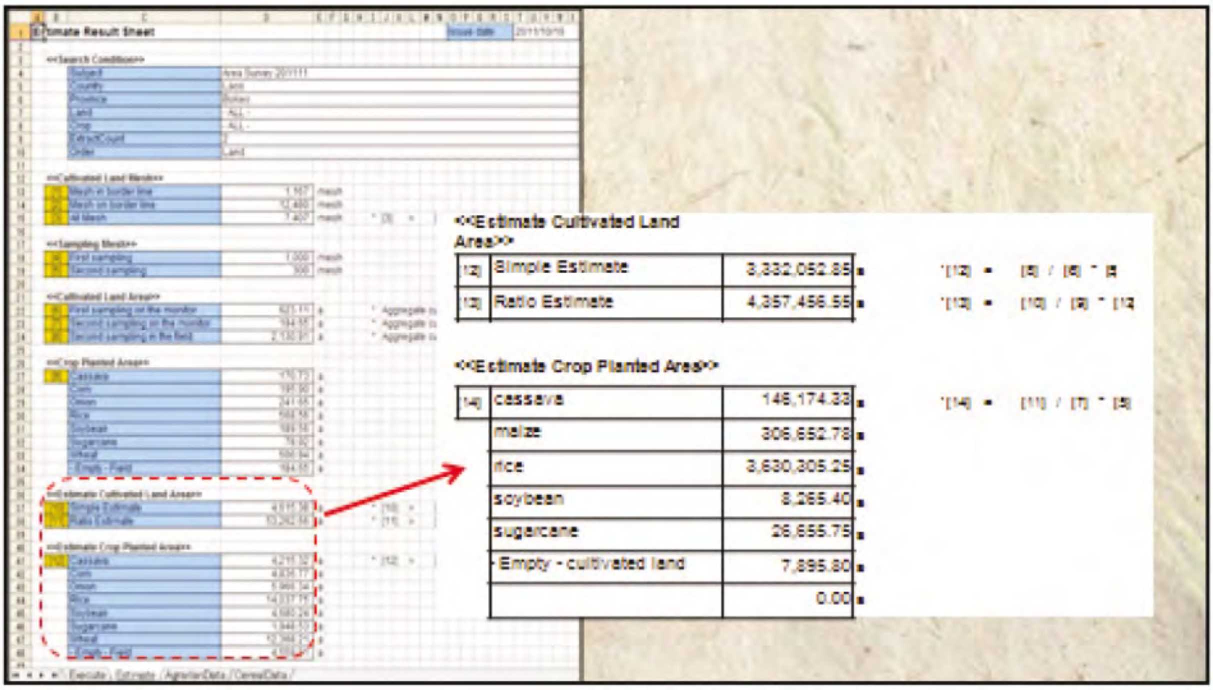

Figure 4. ALIS result sheet

Finally, ALIS makes a result sheet by using the CSV file. In addition, ALIS saves all data areas by each mesh ID to the database.

6. Master sample method

ALIS adopts the "master sample method" to reduce the operation work. The master sample method is one of the statistical sample design methods which is considered to reduce the labour of frame maintenance. Under this method, the master sample meshes are extracted from the original mesh file (first sampling), gives framework information (calculated area of agricultural land by tracing its border line) to these extracted master sample meshes, and then extracts survey sample meshes (second sampling) from this master sample mesh file.

The details of the Master Sample method in ALIS is shown in a study report *Consideration of statistical accuracy on Master Sample method* written by the AFSIS Expert.

7. ALIS operation flow

The ALIS operation flow is determined based on the Master Sample Method: Confirmation of target province border line – Making wide mesh and area mesh (N) – Registration of area mesh which includes agricultural land (N') – First sampling (n) – Addition of area information to "n" – Second sampling (n') – Print out wide map and survey sheet = Field survey = Input the result of field survey to "n" – Estimation of agricultural land area and crops planted area.

ALIS makes four mesh files, i.e. the original mesh file (N), a framework mesh file (N'), the master file of mesh (n), and a sample file of mesh (n') using the master sample method. Figure 4 shows an outline of the ALIS operation flow. We can see that every task in estimation of area data has been completed by ALIS except the field survey.

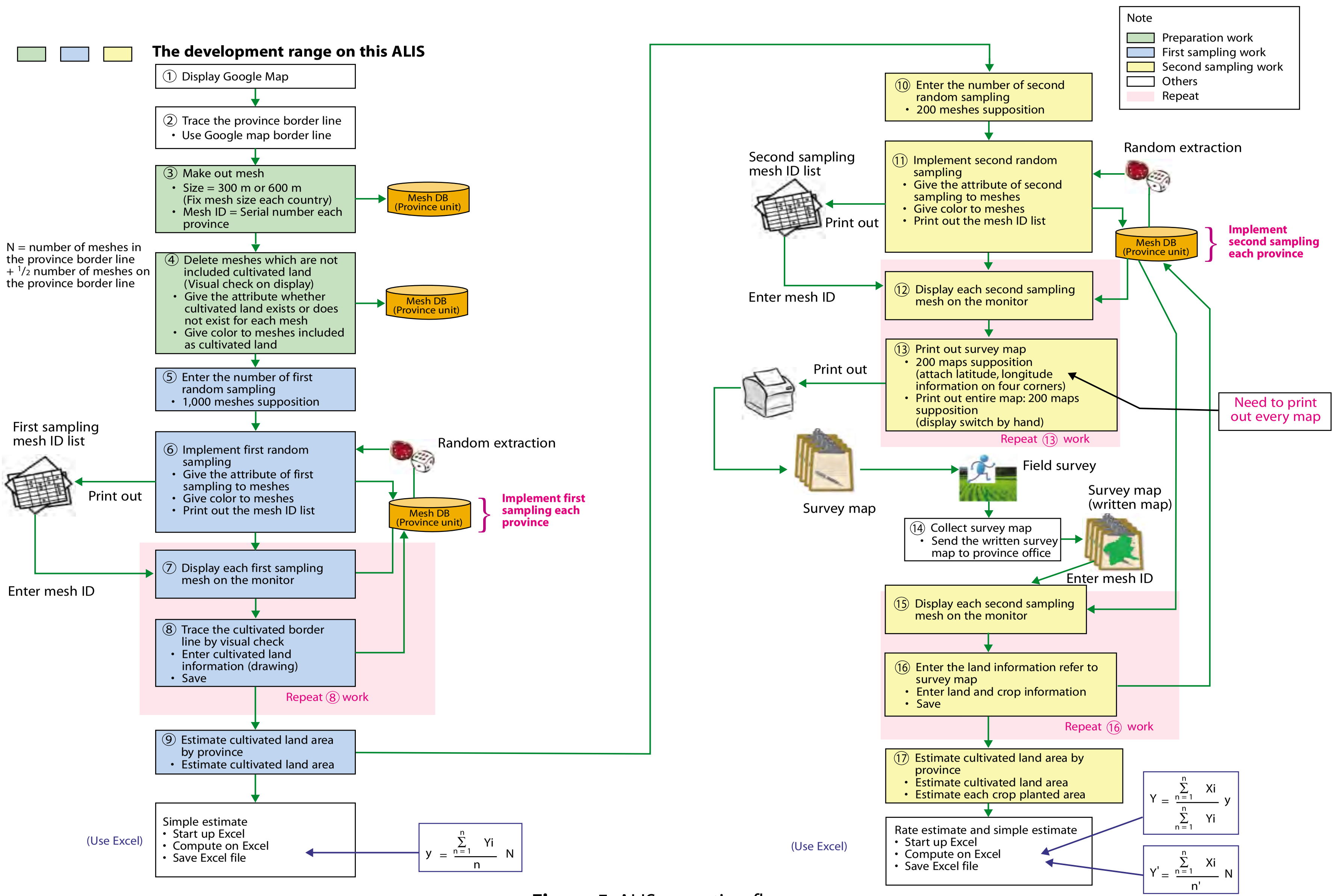

Figure 5. ALIS operation flow

8. Estimation of area data

ALIS can estimate the agricultural land area by province and the planted area of rice, maize, soybean, sugarcane, cassava and another two crops by country. ALIS itself does not have an area estimation function. Instead, the officials do the estimation by using CSV files that have been downloaded from ALIS. Agricultural land area is calculated based on comparison ratio estimation and the planted area by each crop based on simple estimation. The estimation results are printed out as an estimation sheet.

Incidentally, area meshes in wide meshes, including province border line, come out of the sampling target in the initial setting of ALIS. This is a result of consideration of the survey conditions of the surrounding national border line. However, these area meshes become the target of area estimation by rational estimation from the cultivated conditions of area meshes not including the province border line. Moreover, ALIS has a specific function which changes area meshes in wide meshes including province border line, to a sampling target mesh for small area provinces.

The agricultural land area data are calculated by ALIS with following formula:

$$Y = \frac{\sum_{n'=1}^{n'} x_i}{\sum_{n'=1}^{n'} y_i} y \qquad y = \frac{\sum_{n=1}^{n} y_i}{n} N$$

The notations used to describe this formula based on the ALIS operation appear below:

Y = Estimated agricultural land area of the province
y = Estimated agricultural land area by measurement of Google Map
N = Total number of meshes including agricultural land
n = Number of first sampling meshed
n' = Number of second sampling meshes
y_i = Agricultural land area on i-th number mesh of first sample by measurement of Google Map
x_i = Agricultural land area on i-th number mesh of second sample by field survey

The crop planted area data are calculated by ALIS with following formula:

$$Y' = \frac{\sum_{i=1}^{n'} x_i}{n'} N$$

The notations used to describe this formula based on the ALIS operation appear below:

Y' = Estimated crops planted area of this province
N = Number of meshes including agricultural land
n' = Number of second sampling meshes
x_i = Crop planted area on i-th number mesh of second sample by field survey

9. Conclusion of ALIS function

The function of ALIS is to provide a tool for an area sample survey method as a package. The person in charge of area surveys can make the framework, design the survey scale according to target accuracy, extract samples, make survey sheets and estimate the statistical area data by using ALIS. On the other hand, ALIS is a centralized management system. The central office can conduct overall management of sample survey from survey design to estimates of statistical area data while the local office is responsible for conducting the field survey.

ALIS is particularly useful for the countries where neither an area survey nor an area framework has been developed.

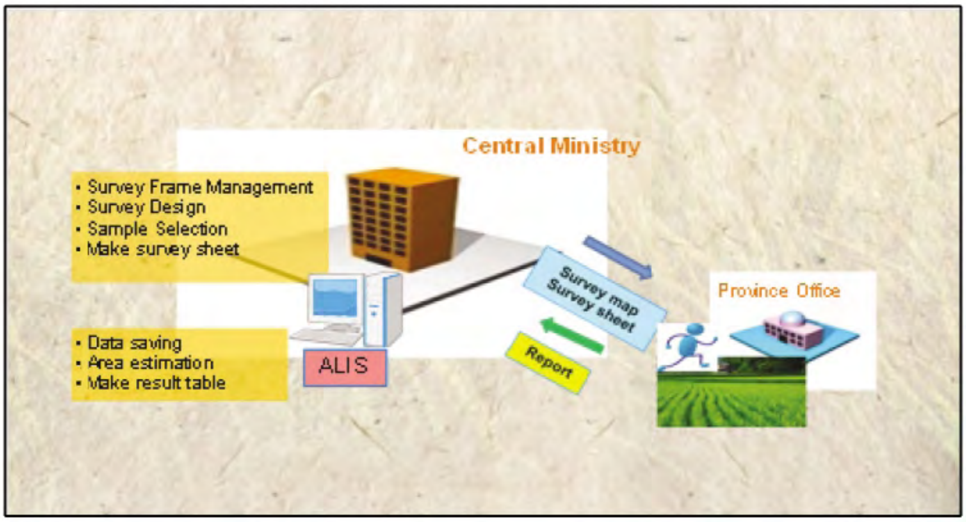

Figure 6. ALIS Centralized Management System

10. Implementation of feasibility study

A feasibility study was implemented in 2011 in order to confirm ALIS operations and verify the estimated data produced by ALIS. Lao PDR and the Kingdom of Cambodia are target countries requested to designate a consultant for implementation of the feasibility study. This consultant was tasked to support the activity of the AFSIS expert and was responsible for field surveys, researcher meetings and ALIS operations in their countries. Figure 7 shows the operation schedule of the feasibility study in Lao PDR. It has taken four months of operations to get the estimated area data. Surprisingly, these operations have mostly been completed by one staff, excluding the field survey.

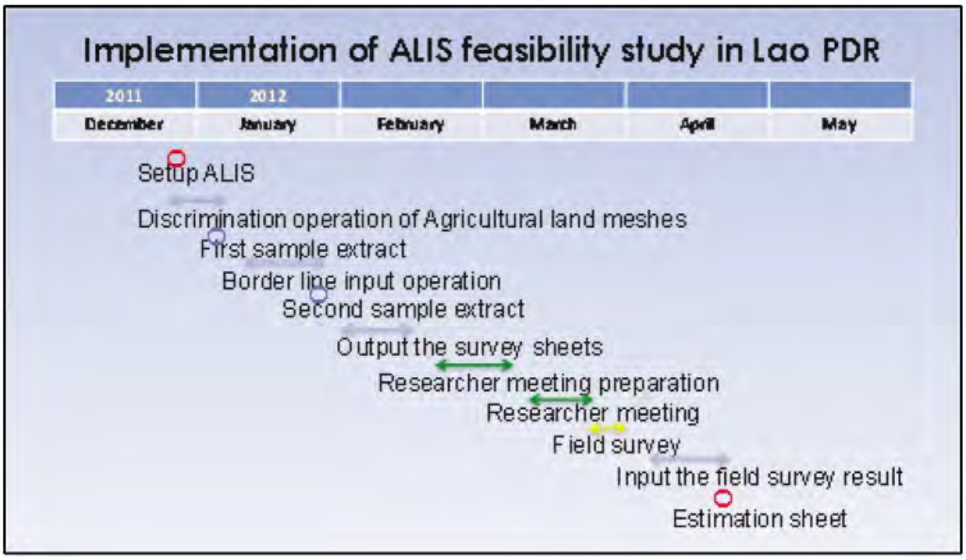

Figure 7. ALIS operation schedule in Lao PDR

11. Field survey

The field survey is the most important process in this feasibility study and it requires a correct survey to ensure the data accuracy. The *Survey operating manual for the national consultant* gives the specific details for the field survey.

Field surveys for the feasibility study have been implemented in Vientiane province, Lao PDR and Kandal province in the Kingdom of Cambodia. Fortunately, we could implement the feasibility study in two provinces that have different land types. In fact, Vientiane province is located in a mountain area while Kandal province is located in a plain field area if we compare with each "agricultural land mesh rate."

Table 1 indicates the fundamental indicators of two provinces in the feasibility study.

Table 1. Fundamental indicator of target provinces on feasibility study

Fundamental indicator	Vientiane province	Unit	Kandal province	Unit
Number of total mesh (300 m mesh)	121 152	mesh	35 456	mesh
Number of mesh including agricultural land (Area framework)	5 500	mesh	13 509	mesh
Agricultural land mesh ratio	4.5	%	38.1	%
Number of first sample mesh*	957	mesh	837	mesh
First sample extraction ratio	17.4	%	6.2	%
Average area of first sampling	6.33	ha	7.99	ha
Number of second sample mesh*	194	mesh	173	mesh
Second sample extraction ratio	3.5	%	1.3	%
Average area of second sampling	7.46	ha	8.45	ha
Average area of second sampling by field survey	7.92	ha	8.86	ha

* It shows the number of sample meshes which actually has been conducted survey.

The AFSIS Expert has prepared the *Area Survey Manual for Researches* for the field survey.

12. Verification of estimated area data on feasibility study

12.1 Formula of accuracy rate

The accuracy rate of agricultural land area data is calculated by using the following formulas through standard error. These standard errors are led by the rate of sample size for framework size and standard error of data average.

a) The formula to obtain the accuracy rate on estimation of agricultural land area (Y) in the first sample:

$$\sigma^2 = \frac{\Sigma(y_i - \bar{y})^2}{n-1} \qquad SE\bar{y} = \sqrt{\frac{N-n}{N}}\frac{\sigma}{\sqrt{n}}$$

b) The formula to obtain the accuracy rate of the area change rate in the second sample:

$$+\ \sigma^2(xi - Ry) = \frac{\Sigma(x_i - \hat{R}yi)^2}{n-1} \qquad SE\bar{x} = \sqrt{\frac{N-n}{N}}\frac{\sigma}{\sqrt{n'}}$$

c) The formula for the whole accuracy rate calculation on agricultural land area:

$$SEY = \sqrt{SE^2\bar{y} + SE^2\hat{x}}$$

The accuracy rate of crop planted area data is calculated by standard error using the following formula.

$$\sigma^2 = \frac{\sum(x_i - \bar{x})^2}{n' - 1} \qquad SE\bar{x} = \sqrt{\frac{N - n'}{N}}\frac{\sigma}{\sqrt{n'}}$$

12.2 Standard error of estimated area data

Table 2. Results of target provinces feasibility studies

	Vientiane province			Kandal province		
	$\bar{y}$	SEY	$SERY$	$\bar{y}$	SEY	$SERY$
Agricultural land area	7.92 ha	0.250 ha	3.4%	8.38 ha	0.212 ha	2.4%
Crop planted area	$\bar{x}$	$SE\bar{x}$	$SER\bar{x}$	$\bar{x}$	$SE\bar{x}$	$SER\bar{x}$
Rice	6.60 ha	0.248 ha	3.8%	8.11 ha	0.226 ha	2.8%
Mais	0.56 ha	0.081 ha	14.4%	0.38 ha	0.115 ha	30.2%
Cassava	0.27 ha	0.082 ha	30.8%	…	…	…
Sugarcane	0.05 ha	0.028 ha	58.5%	0.10 ha	0.053 ha	51.6%
Soybean	0.02 ha	0.015 ha	98.7%	…	…	…

Table 2 shows the standard error and standard error rate of estimated agricultural land area and each targeted crop planted area by province. The results of each crop planted area, excluding rice, are led by the small appearance rate for samples. It needs to consider the solution and statistical approach for the minor crops based on this result.

In addition, we have to consider that these accuracy rates are not for only area data but also the ALIS method is the beginning of the Master Sample Method. In other words, the accuracy rate for the true value assumes the totally completed ALIS operation and the error-free implementation of the field survey; however, the standard error rate itself appears to be a good result.

The detail of accuracy calculation including the consideration for target accuracy and the number of samples in ALIS are shown in a study report *Accuracy Calculation in ALIS* written by the AFSIS Expert.

13. Adjustment function of ALIS

Generally speaking, it is a quite rare that the results of a sample survey can be used as public announcement data. The final goal of the ALIS program targets the public announcement of area data. So data adjustment work is required in the middle of statistical operations in some cases.

Figure 8 shows a simple outline of ALIS operation. ALIS operation was one-way in the original design. After the feasibility study, ALIS now has three routes for data correct operation. One is for adjustment of the number of extracted agricultural land meshes. Second is for adjustment of input area data for first samples. Third is for adjustment of input field survey data. The ALIS operation style has changed from a one-way operation to a workflow operation by this revision.

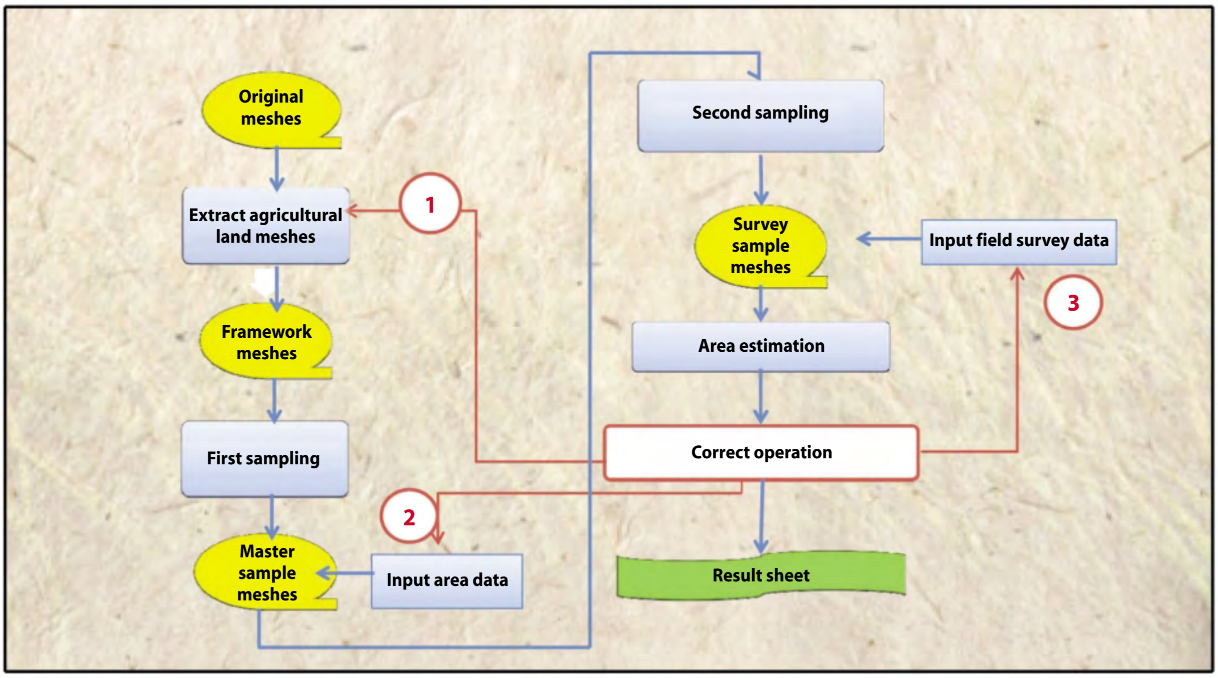

Figure 8. Adjustment function of ALIS

Adoption of Agricultural Land Information System (ALIS) for agricultural area estimation

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ABSTRACT

The importance of timely and reliable agricultural statistics to achieve food security in the Philippines cannot be overemphasized. The current gaps in the agricultural statistics production system necessitate the adoption of sustainable methodologies that will provide accurate and up-to-date estimates of staple food crops. These challenges have been recognized and addressed by ASEAN member countries through the ASEAN Food Security Information System (AFSIS). One of the methodologies developed under AFSIS is the Agricultural Land Information System (ALIS), which provides estimates of areas planted to major crops using satellite imagery that can be accessed free of charge, supporting area sample surveys for countries having non-developed area surveys. After its successful implementation in Lao PDR and Cambodia, ALIS was also adopted in the Philippines through the Bureau of Agricultural Statistics to evaluate its use in estimating total agricultural land area and crop planted area.

ALIS was pilot tested in Nueva Ecija. Sample meshes were selected using the simple two-stage sampling technique wherein field validation was done in the second stage to evaluate the accuracy of agricultural land area measurements. ALIS generated an estimate of the total agricultural land area of the province and estimates of total area planted to major crops. Results showed that there are differences between the agricultural land area measurements from Google Maps and the field survey. However, the differences can be considered acceptable. Hence, estimates derived using ALIS are considered reliable estimates of the total agricultural land area in the province. For the crop planted area, only the estimate for rice planted areas in the province is considered reliable. To further assess the level of accuracy of the system, another round of validation may be conducted during another cropping season. It is also recommended to evaluate the same system in other provinces in the country. There is also need to further enhance the use of remote sensing technologies in the country in generating agricultural statistics.

1. Introduction

Food Security is a priority programme of the Department of Agriculture, Philippines and is one of the agency's most pressing challenges amidst the effects of climate change, demands for natural resources and competing food crop use. The importance of the agriculture sector for achieving food security demands that its planning, management, and monitoring be based on sound evidence. This, in turn, requires the sustained availability of comprehensive, reliable and up-to-date statistical data. Having accurate and reliable information will help policy makers in formulating polices and strategies for the development of the sector.

The current agricultural statistics production system in the country is based on the administrative reporting system. The reports are filled at the barangay level, by observing harvests or by interviewing experts, and progressively summarized at the municipal, provincial and national levels. Though sustainable and inexpensive, this method is also unreliable and prone to biases and measurement errors. In addition, the administrative reporting system does not usually include a validation method that could improve the quality of estimates. Censuses and surveys, on the other hand, can provide better estimates. These methods, however, require a larger budget and usually take a longer time to process. These gaps in the agricultural statistics production system prompted the adoption and institutionalization of appropriate and sustainable methodologies that will provide timely and reliable estimates of staple food crops.

Since the introduction of the objective method for estimation of crop statistics, steps have been taken from time to time for improvement of agricultural statistics in terms of coverage, scope, accuracy, standardization and coordination (Narain 2002). The applications of information technology systems have been widely used and documented. There are many studies using remote sensing data for improving the estimates obtained from area sampling. Use of GPS has also allowed data collection become more accurate and consistent than estimating locations or area using paper maps and distance measurement. GIS on the other hand, has important applications which include monitoring of crops, management of precision farming practices and area frame survey support (Martinez 2013).

The challenge of food security and the issues on the reliability of statistical data have been recognized and addressed by ASEAN member countries through the ASEAN Food Security Information System (AFSIS). AFSIS is one of the interventions of the ASEAN+3 Cooperation Framework, which aim to strengthen food security in the region through the systematic collection, analysis and dissemination of food security-related information. The project was started in 2003 with two phases. Phase I, which was completed in 2007, focused on data collection, database website development and capacity building activities. Phase II, which is on-going, continues most of Phase I activities but with the addition of more analytical studies that would help guide policy makers in strategizing more rapid achievement of food security in the region.

One of the methodologies developed under AFSIS is the Agricultural Land Information System (ALIS). ALIS is a system that provides estimates of areas planted to major crops such as rice, maize, cassava, sugarcane and soybean using satellite imagery that can be accessed free of charge (e.g Google map), supporting area sample surveys for countries having non-developed area surveys. ALIS was first adopted and successfully implemented by AFSIS in Vientiane Province, Lao PDR and in Kandal Province, Cambodia (Kimura 2012).

The Bureau of Agricultural Statistics (BAS) of the Department of Agriculture is mandated to collect, compile and release official agricultural statistics. In pursuit of its mandated tasks, the agency continues to adopt methodologies that will improve the quality of agricultural statistics. This paper aims to study the use of ALIS for agricultural area estimation. Specifically it aims to:

1. apply existing remote sensing technology in estimating agricultural land areas; and
2. estimate total agricultural land area and crop planted area of the pilot province.

BAS adopted ALIS through the support of ADB under its regional policy and advisory technical assistance (R-PATA) 8029: Improving Agricultural and Rural Statistics for Food Security. One of the major activities of R-PATA 8029 is to conduct methodological research through special studies and application of affordable data collection strategies for agricultural and rural statistics. The main functions of ALIS include: 1) the development of an agricultural land mesh framework; 2) area estimation; and 3) survey support, and are directly related to the objectives of R-PATA 8029.

2. Conceptual framework

ALIS was used to compute the estimates of total agricultural land area and crop areas for three crops in Nueva Ecija using Google Map, which will be explained further in the Methodology section of this paper. This section presents the statistical concepts that were used in deriving and validating the area estimates.

The basic computation of this measurement approach is to divide the provincial area into 24 021 meshes and identify the land use for each of the meshes. Sample meshes are then selected using the simple two-stage sampling technique. Data on agricultural land area for the first sample were measured using only Google Map and the ALIS software, while data for the second sample includes validated agricultural land areas from the field survey conducted. Crop area estimates are then derived for the second stage with the estimates based on data from the field survey.

2.1 Estimation of total agricultural land area

Estimate of total agricultural land area based on the first sample

Based on initial agricultural land area measurements from Google Map, the ALIS generates a weighted estimate of the total agricultural land area $\hat{\tau}_{agri1}$ in the province computed as

$$\hat{\boldsymbol{\tau}}_{\boldsymbol{agri1}} = \sum_{i=1}^{n_1} \boldsymbol{x_i} \cdot \left(\frac{\boldsymbol{N}}{\boldsymbol{n_1}}\right) \tag{1}$$

where x_i is the agricultural land area for the i[th] sampled mesh based on measurements from Google Map, n_1 is the size of the first sample, and N is the total number of agricultural land meshes in the province.

To measure the accuracy of this estimate, an estimate of the standard error of $\hat{\tau}_{agri1}$ was computed. The estimate of the standard error of $\hat{\tau}_{agri1}$ is computed as

$$\widehat{SE}\left(\hat{\boldsymbol{\tau}}_{\boldsymbol{agri1}}\right) = \sqrt{\boldsymbol{N}(\boldsymbol{N} - \boldsymbol{n_1}) \cdot \frac{\boldsymbol{s_x^2}}{\boldsymbol{n_1}}} \qquad \text{where} \qquad \boldsymbol{s_x^2} = \frac{\boldsymbol{1}}{\boldsymbol{n_1 - 1}} \sum_{i=1}^{n_1} (\boldsymbol{x_i} - \overline{\boldsymbol{x}})^{\boldsymbol{2}} \tag{2}$$

The coefficient of variation was also computed as

$$\boldsymbol{CV}(\hat{\boldsymbol{\mu}}_{\boldsymbol{agri1}}) = \frac{\widehat{SE}\left(\hat{\boldsymbol{\mu}}_{\boldsymbol{agri1}}\right)}{\hat{\boldsymbol{\mu}}_{\boldsymbol{agri1}}} \tag{3}$$

where $\hat{\mu}_{agri1}$ refers to the estimated mean agricultural land area while $\widehat{SE}\left(\hat{\mu}_{agri1}\right)$ refers to the estimate of the standard error of $\hat{\mu}_{agri1}$.

To validate the agricultural land area measurements based on Google Map and to determine the accuracy of these measurements, field verification was done. Agricultural land area measurements from a second set of sample meshes were verified in the field. The second set of sample meshes were selected from the first sample. Based on the result of the field survey and upon completion of the map survey registration in ALIS, a ratio estimate of the total agricultural land area in the province was computed.

Ratio estimate of total agricultural land area

Ratio estimation is a statistical technique that makes use of an auxiliary variable in order to estimate the parameter value of a variable of interest. This statistical technique calls for an auxiliary variable that can be easily measured from the whole population while the response variable is more difficult or more expensive to measure and is usually obtained from a simple random sample of the population.

In this study, the agricultural land area based on measurements from Google Maps was used as the auxiliary variable. Using freely available maps from Google and with the use of the ALIS software, agricultural land areas within a province can be easily measured. On the other hand, validated agricultural land areas from the field can be measured only from selected areas in the province because field surveys require more resources and are usually expensive to conduct.

The ratio estimate of the total agricultural land area $\hat{\tau}_{R,agri}$ was computed as

$$\hat{\boldsymbol{\tau}}_{R,agri} = \boldsymbol{r} \cdot \hat{\boldsymbol{\tau}}_{agri1} = \frac{\overline{\boldsymbol{y}}}{\overline{\boldsymbol{x}}} \cdot \hat{\boldsymbol{\tau}}_{agri1} = \frac{\sum_{i=1}^{n_2} y_i/n_2}{\sum_{i=1}^{n_2} x_i/n_2} \cdot \hat{\boldsymbol{\tau}}_{agri1} \quad (4)$$

where r is the sample ratio, x_i is the agricultural land area for the i^{th} sampled mesh based on measurements from Google Maps, y_i is the agricultural land area for the i^{th} sampled mesh based on the field survey, n_2 is the number of meshes in the second sample, and $\hat{\tau}_{agri1}$ is the estimate of the total agricultural land area based on the first sample.

Similarly, estimate of the standard error of $\hat{\tau}_{R,agri}$ and the coefficient of variation were also computed. The estimate of the standard error of $\hat{\tau}_{R,agri}$ is computed as

$$\widehat{SE}\left(\hat{\tau}_{R,agri}\right) = \sqrt{N(N-n_2) \cdot \frac{s_r^2}{n_2}} \quad \text{where} \quad s_r^2 = \frac{1}{n_2 - 1}\sum_{i=1}^{n_2}(y_i - rx_i)^2 \quad (5)$$

while the coefficient of variation is computed as

$$CV(\hat{\mu}_{R,agri}) = \frac{\widehat{SE}\left(\hat{\mu}_{R,agri}\right)}{\hat{\mu}_{R,agri}} \quad (6)$$

where $\hat{\mu}_{R,agri}$ refers to the ratio estimate of the mean agricultural land area while $\widehat{SE}\left(\hat{\mu}_{R,agri}\right)$ refers to the estimate of the standard error of $\hat{\mu}_{R,agri}$.

To compute the overall accuracy of the total agricultural land area estimate, and to account for the total variation due to the first and second sampling, the overall standard error and coefficient of variation were computed, respectively, as

$$\widehat{SE}(\hat{\tau}_{overall}) = \sqrt{\widehat{SE}^2\left(\hat{\tau}_{agri1}\right) + \widehat{SE}^2\left(\hat{\tau}_{R,agri}\right)} \quad (7)$$

and

$$CV(overall) = \sqrt{CV^2\left(\hat{\mu}_{agri1}\right) + CV^2\left(\hat{\mu}_{R,agri}\right).} \quad (8)$$

2.2 Estimation of total crop planted area

In addition, ALIS also generates estimates of total area planted for selected crops $\hat{\boldsymbol{\tau}}_{\boldsymbol{crop_j}}$ based on crop planted areas validated in the field. Planted areas were estimated for crops including rice, corn, cassava, and others. For each crop, estimate of total area planted was computed as

$$\hat{\boldsymbol{\tau}}_{\boldsymbol{crop_j}} = \sum_{i=1}^{n_2} \boldsymbol{y_{ij}} \cdot \left(\frac{\boldsymbol{N}}{\boldsymbol{n_2}}\right) \tag{9}$$

where y_{ij} is the crop planted area for the i^{th} sampled mesh and the j^{th} crop based on the field survey, n_2 is the number of meshes sampled from the master sample, and N is the total number of agricultural land meshes in the province.

Likewise, the standard error and the coefficient of variation of $\hat{\boldsymbol{\tau}}_{\boldsymbol{crop_j}}$ for each crop were also computed. The estimate of the standard error of $\hat{\boldsymbol{\tau}}_{\boldsymbol{crop_j}}$ is computed as

$$\widehat{\boldsymbol{SE}}\left(\hat{\boldsymbol{\tau}}_{\boldsymbol{crop_j}}\right) = \sqrt{\boldsymbol{N}(\boldsymbol{N}-\boldsymbol{n_2}) \cdot \frac{\boldsymbol{s}^2_{\boldsymbol{y_j}}}{\boldsymbol{n_2}}} \qquad \textit{where} \qquad \boldsymbol{s}^2_{\boldsymbol{y_j}} = \frac{\boldsymbol{1}}{\boldsymbol{n_2}-\boldsymbol{1}}\sum_{i=1}^{n_2}\left(\boldsymbol{y_{ij}} - \overline{\boldsymbol{y}}_{.j}\right)^2 \tag{10}$$

while the coefficient of variation is computed as

$$\boldsymbol{CV}(\widehat{\boldsymbol{\mu}}_{\boldsymbol{crop_j}}) = \frac{\widehat{\boldsymbol{SE}}\left(\widehat{\boldsymbol{\mu}}_{\boldsymbol{crop_j}}\right)}{\widehat{\boldsymbol{\mu}}_{\boldsymbol{crop_j}}} \tag{11}$$

where $\hat{\mu}_{crop_j}$ refers to the estimate of the mean crop planted area of the j^{th} crop, while $\widehat{SE}\left(\hat{\mu}_{crop_j}\right)$ refers to the estimate of the standard error of $\hat{\mu}_{crop_j}$.

2.3 Comparison of agricultural land area measurements

Agricultural land area measurements estimated using only Google Map and the ALIS software were compared vis-à-vis the agricultural land area measurements that were validated from the field. This was done to assess the accuracy of estimates derived using remote sensing technologies, such as the use of Google Map in estimating agricultural statistics, specifically, agricultural land areas.

The difference in agricultural land area measurements was computed as

$$\boldsymbol{d_i} = \boldsymbol{x_i} - \boldsymbol{y_i}; \quad \boldsymbol{for} \quad \boldsymbol{i} = \boldsymbol{1}, \boldsymbol{2}, \dots, \boldsymbol{n_2} \tag{12}$$

where x_i is the agricultural land area for the i^{th} sampled mesh based on measurements from Google Map, y_i is the agricultural land area for the i^{th} sampled mesh based on the field survey, and n_2 is the number of meshes in the second sample.

The appropriate statistical test for paired samples was done after checking necessary assumptions that the population differences, d_i's are normally distributed with mean μ_D and variance σ_D^2; and that the two samples came from normally-distributed populations.

3. Methodology

The BAS management initiated the creation of a working group tasked to plan and implement the activities for the adoption of ALIS. The ALIS software was installed at the GIS Laboratory of BAS and can be accessed from five client computers.

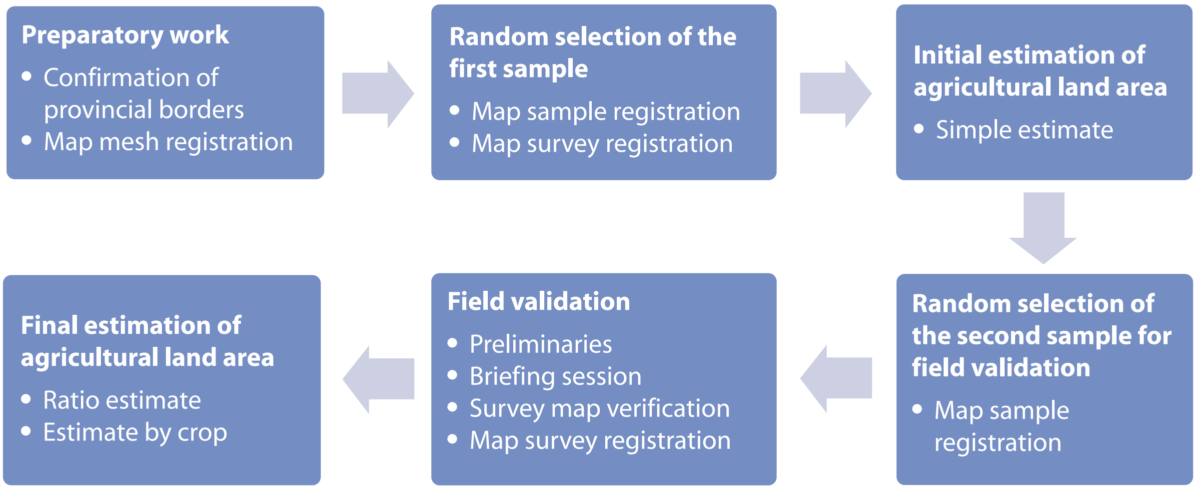


Figure 1. ALIS Workflow

3.1 Preparatory work

The province of Nueva Ecija was selected as the pilot province due to its intensive and diverse cropping, and its proximity to the BAS Central Office in Manila. For the selected area, 300 m x 300 m area meshes were used. Each mesh has a designated mesh ID. These area meshes were saved in the database as the original mesh file.

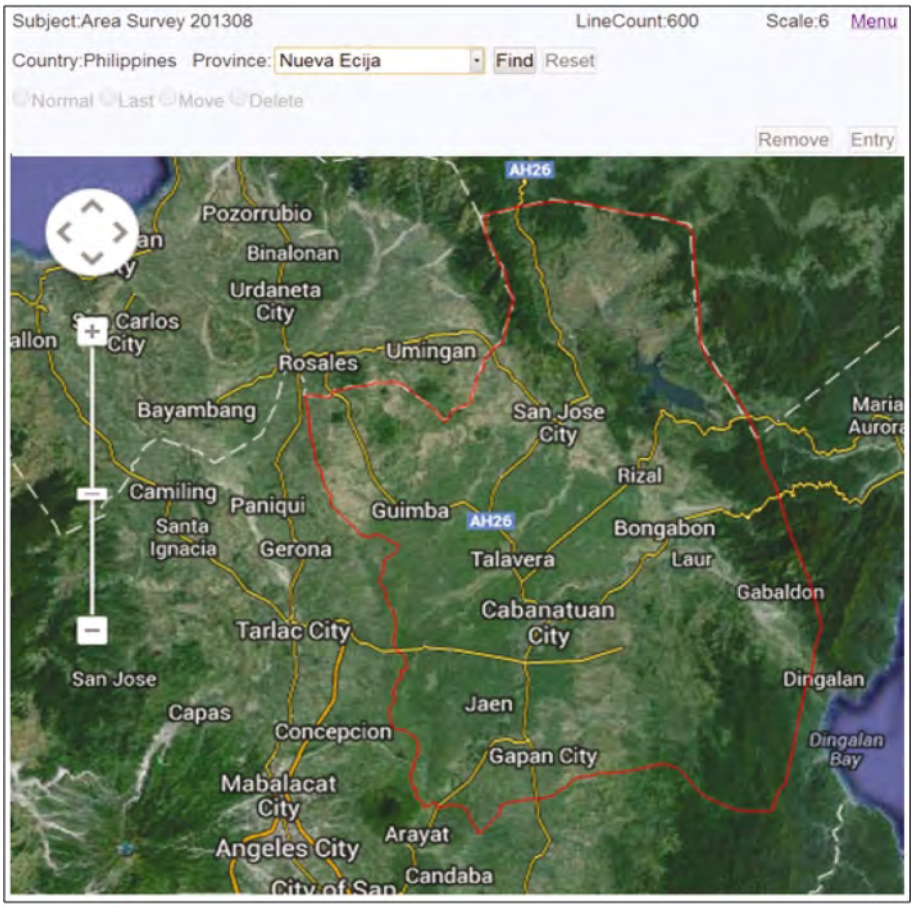


Figure 2. Provincial map of Nueva Ecija

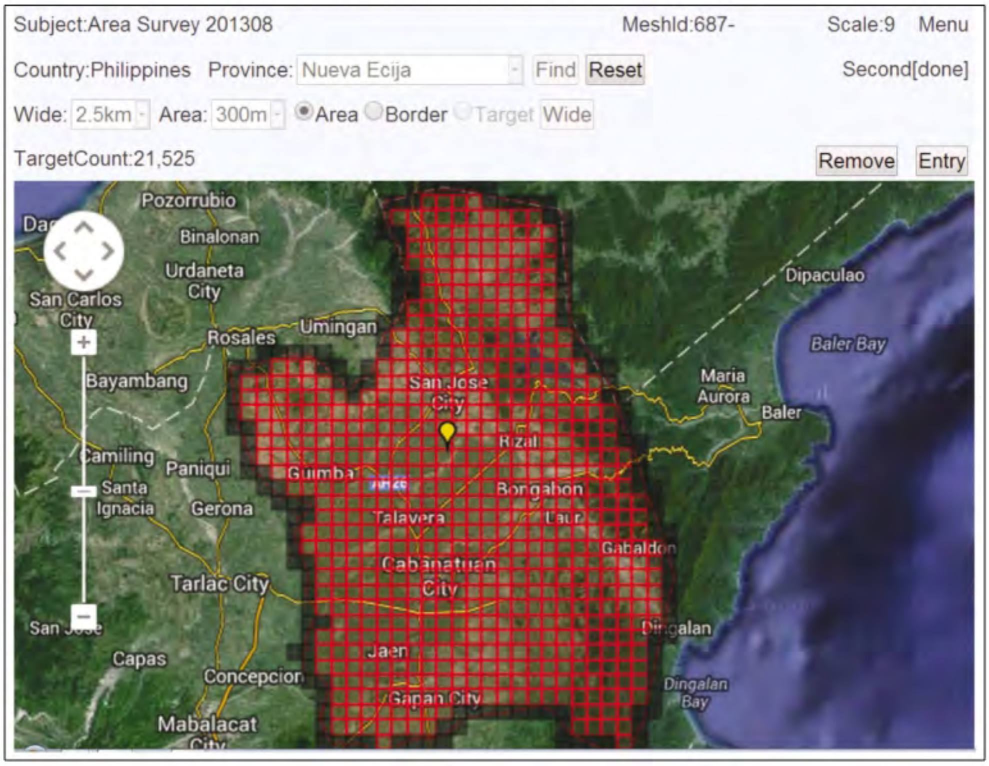


Figure 3. Provincial map with the 300 m x 300 m area meshes

Agricultural land areas were identified in the original mesh file. Meshes having more agricultural areas than non-agricultural were tagged as "agricultural" and identified with the color red, while those which did not show any agricultural land areas were deleted. The criteria used in the mesh classification are in Appendix 1. Map mesh registration took eight (8) days to complete.

3.2 Random selection of the first sample

Using the ALIS software, a simple random sample of 5 000 agricultural land meshes were selected from the 24 021 agricultural land meshes in Nueva Ecija province. Inspection of each mesh in the first sample was done to trace the border corresponding to areas identified as agricultural. This process was completed in five (5) days.

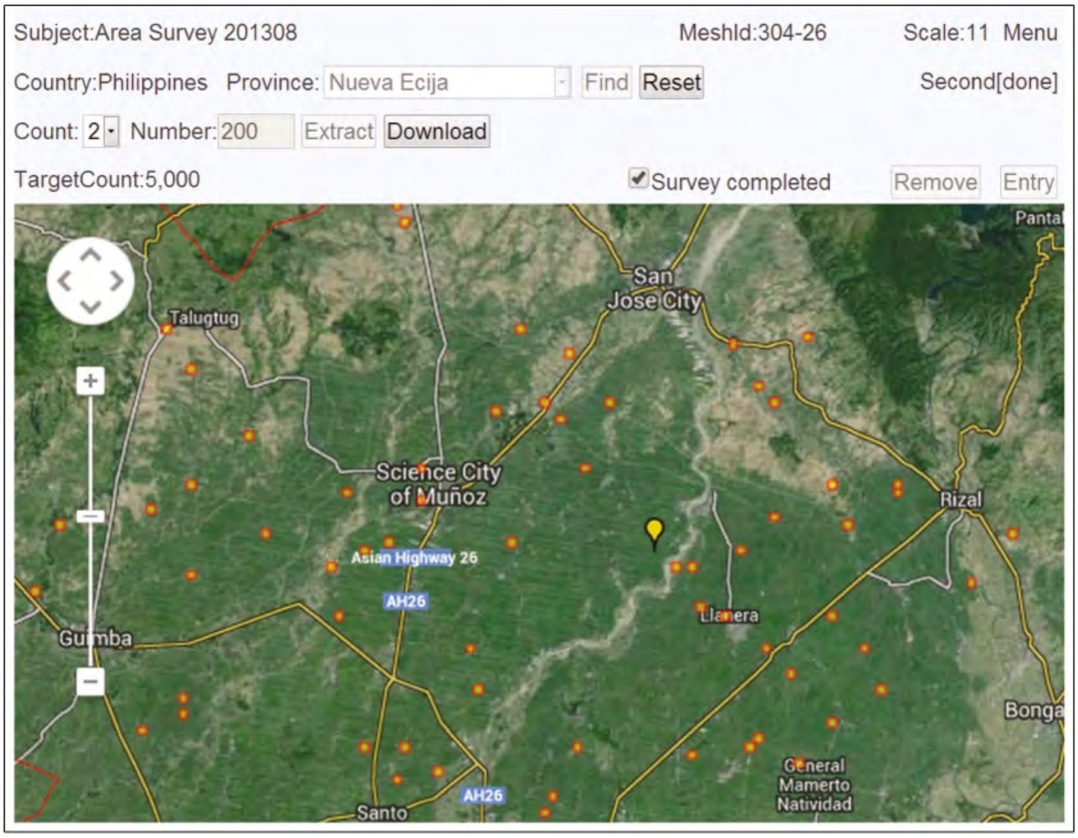


Figure 4. Randomly selected sample meshes

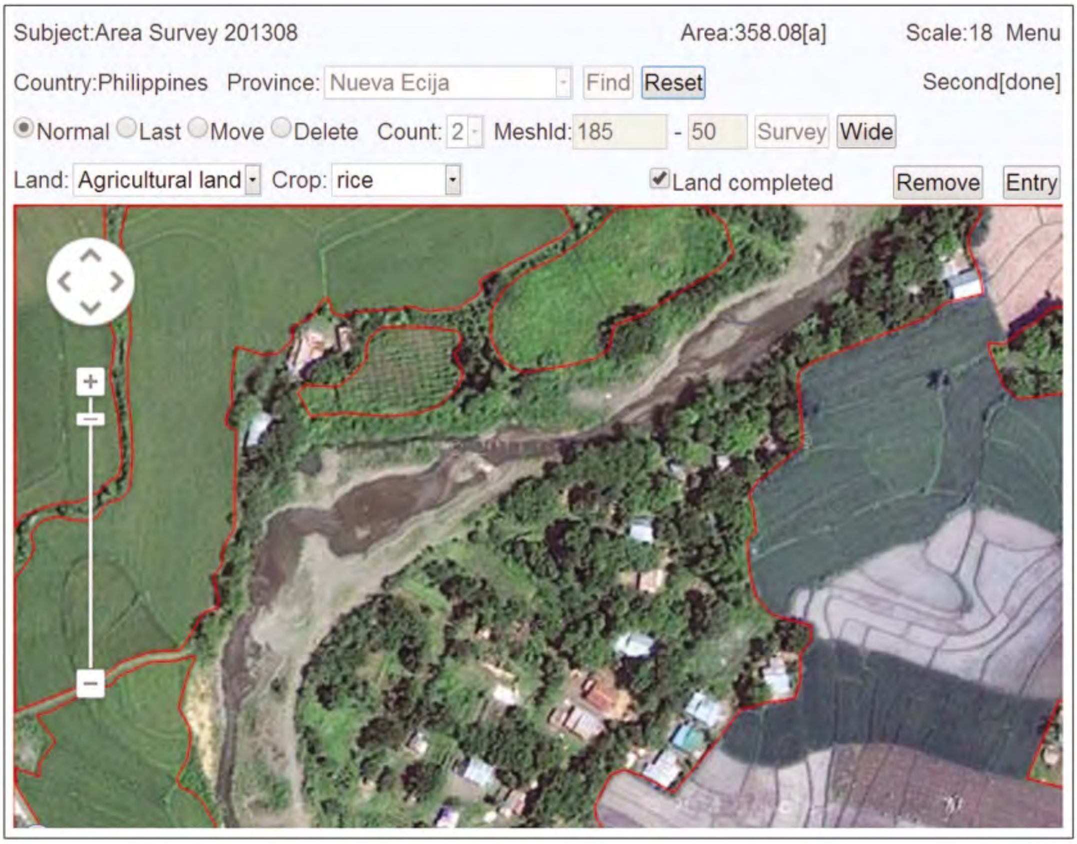


Figure 5. Identification of agricultural land in the area mesh

3.3 Initial estimation of agricultural land area

Based on the first sample, the ALIS generated a simple estimate of the total agricultural land area $\hat{\tau}_{agri1}$ in the province. To measure the accuracy of the estimate of the total agricultural land area, an estimate of the standard error and the coefficient of variation of $\hat{\tau}_{agri1}$ were also computed.

Agrarian Data Sheet								Issue date	Sept. 26, 2013
Subject	Area Survey 201308								

No	Sampling		Country	Province	MeshWideId	MeshAreaId	Land	Area [a]	
	First	Second						First	Second
1	Yes		Philippines	Nueva Ecija	7	1	Agricultural land	1176.53	0
2	Yes		Philippines	Nueva Ecija	7	4	Agricultural land	1176.64	0
3	Yes		Philippines	Nueva Ecija	7	5	Agricultural land	1179.17	0
4	Yes		Philippines	Nueva Ecija	7	8	Agricultural land	1016.84	0
5	Yes		Philippines	Nueva Ecija	7	15	Agricultural land	1169.07	0
6	Yes		Philippines	Nueva Ecija	7	17	Agricultural land	1110	0
7	Yes		Philippines	Nueva Ecija	7	20	Agricultural land	1152.8	0
8	Yes		Philippines	Nueva Ecija	7	21	Agricultural land	1147.77	0
9	Yes		Philippines	Nueva Ecija	7	22	Agricultural land	918.64	0
10	Yes		Philippines	Nueva Ecija	7	23	Agricultural land	607.62	0
11	Yes		Philippines	Nueva Ecija	7	29	Agricultural land	286.67	0
12	Yes		Philippines	Nueva Ecija	7	31	Agricultural land	1149.14	0
13	Yes		Philippines	Nueva Ecija	7	35	Agricultural land	1037.12	0
14	Yes		Philippines	Nueva Ecija	7	39	Agricultural land	1103.31	0
15	Yes		Philippines	Nueva Ecija	8	6	Agricultural land	1046.62	0
16	Yes		Philippines	Nueva Ecija	8	7	Agricultural land	967.08	0
17	Yes		Philippines	Nueva Ecija	8	9	Agricultural land	695.41	0
18	Yes		Philippines	Nueva Ecija	8	13	Agricultural land	1182.05	0
19	Yes		Philippines	Nueva Ecija	8	21	Agricultural land	960.59	0
20	Yes		Philippines	Nueva Ecija	8	24	Agricultural land	961.72	0
21	Yes		Philippines	Nueva Ecija	8	33	Agricultural land	1025.33	0
22	Yes		Philippines	Nueva Ecija	8	34	Agricultural land	1052.42	0

Figure 6. First sample area estimates

3.4 Random selection of the second sample for field validation

From the first sample, a simple random sample of 200 meshes was drawn. Agricultural land areas for these sampled meshes were verified in the field survey. Four copies of each of the survey maps were printed on an A3-sized paper as shown in Figure 6: a) the survey district map (upper map); and b) the survey district map containing information on the coordinates of the survey district (lower map).

Figure 7. Survey district map

3.5 Field validation

After a briefing session, six teams each comprising three members were deployed to conduct the survey of the 200 sample meshes. The names of BAS Central Office personnel and provincial statistical officers and their corresponding mesh assignments are listed in Appendix 2. Each team was provided with a GPS device to aid in identifying and matching the actual area to the printed area maps. Two copies of the survey maps were also provided to each team – one copy (Map A) was used during the survey, while the other copy (Map B) was submitted to the regional office with all information from Map A completely transcribed after the survey.

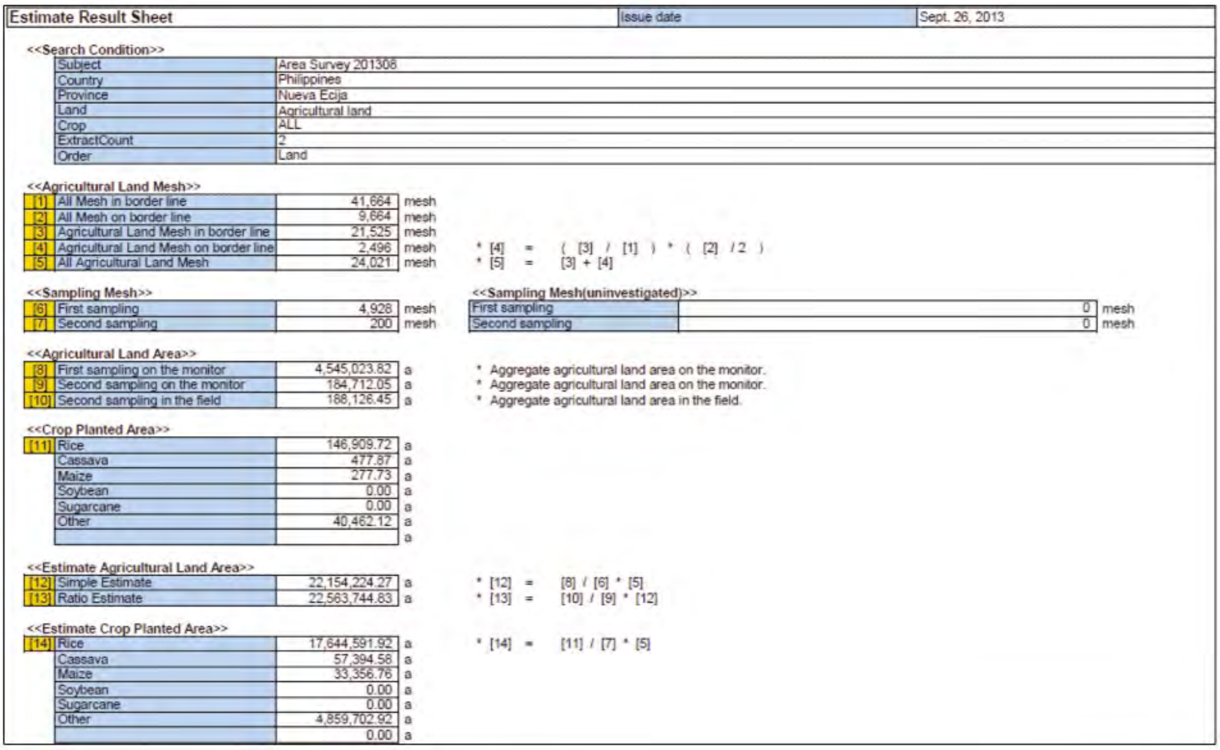
During the survey, the field researchers confirmed the actual topography, crops planted, presence of rivers, road, idle lands, etc. by visual confirmation. Borders were drawn to delineate the area planted to a specific crop from those areas with multiple cropping. In those cases when visual checking could not be done, the researchers interviewed the farmers/owners in the area to determine the actual land use.

Figure 8. Survey sheet

3.6 Final estimation of agricultural land area

Based on the result of the field survey and upon completion of the map survey registration in ALIS for the 200 sampled meshes, ALIS generates a ratio estimate of the total agricultural land area $\hat{\tau}_{R,\,agri}$ in the province. Agricultural land area based on measurements from Google map was used as the auxiliary variable. Similarly, estimates of the standard error and the coefficient of variation of $\hat{\tau}_{R,\,agri}$ were also computed.

To compute the overall accuracy of the estimate, the overall standard error and coefficient of variation were computed. In addition, ALIS also generates estimates of total area planted for selected crops $\hat{\boldsymbol{\tau}}_{\boldsymbol{crop_j}}$ including rice, corn, cassava, and others. Likewise, the standard error and the coefficient of variation of $\hat{\boldsymbol{\tau}}_{\boldsymbol{crop_j}}$ for each crop were also computed.



Estimate Result Sheet	Issue date	Sept. 26, 2013

<<Search Condition>>

Subject	Area Survey 201308
Country	Philippines
Province	Nueva Ecija
Land	Agricultural land
Crop	ALL
ExtractCount	2
Order	Land

<<Agricultural Land Mesh>>

[1]	All Mesh in border line	41,664	mesh	
[2]	All Mesh on border line	9,664	mesh	
[3]	Agricultural Land Mesh in border line	21,525	mesh	
[4]	Agricultural Land Mesh on border line	2,496	mesh	* [4] = ([3] / [1]) * ([2] /2)
[5]	All Agricultural Land Mesh	24,021	mesh	* [5] = [3] + [4]

<<Sampling Mesh>>

[6]	First sampling	4,928	mesh
[7]	Second sampling	200	mesh

<<Sampling Mesh(uninvestigated)>>

First sampling	0	mesh
Second sampling	0	mesh

<<Agricultural Land Area>>

[8]	First sampling on the monitor	4,545,023.82	a	* Aggregate agricultural land area on the monitor.
[9]	Second sampling on the monitor	184,712.05	a	* Aggregate agricultural land area on the monitor.
[10]	Second sampling in the field	188,126.45	a	* Aggregate agricultural land area in the field.

<<Crop Planted Area>>

[11]	Rice	146,909.72	a
	Cassava	477.87	a
	Maize	277.73	a
	Soybean	0.00	a
	Sugarcane	0.00	a
	Other	40,462.12	a
			a

<<Estimate Agricultural Land Area>>

[12]	Simple Estimate	22,154,224.27	a	* [12] = [8] / [6] * [5]
[13]	Ratio Estimate	22,563,744.83	a	* [13] = [10] / [9] * [12]

<<Estimate Crop Planted Area>>

[14]	Rice	17,644,591.92	a	* [14] = [11] / [7] * [5]
	Cassava	57,394.58	a	
	Maize	33,356.76	a	
	Soybean	0.00	a	
	Sugarcane	0.00	a	
	Other	4,859,702.92	a	
		0.00	a	

Figure 9. Final agricultural land estimates

To compare the agricultural land area measurements estimated using only Google Maps vis-à-vis the agricultural land area measurements that were validated from the field, appropriate statistical test for paired samples was done.

4. Results and discussion

4.1 Estimates of total agricultural land area

As shown in Table 1 below, the total agricultural land area in Nueva Ecija is estimated at 221 542.24 hectares. This is based on agricultural land area measurements estimated using Google Map for the 4 928 meshes selected from 24 021 total meshes created in ALIS. The estimate of total agricultural land area has a standard error of 872.5 hectares and a coefficient of variation of 0.39 percent. Weighted summary statistics calculated from the sample data are also presented in Appendix 3 Table 1.

Table 1. Total Agricultural Land Area Estimates, Nueva Ecija (in hectares)

Estimate	Value	Standard Error	Coefficient of Variation	Sample Size
Simple estimate	221 542.24	872.56	0.39%	4 928
Ratio estimate	225 637.45	2 960.24	1.31%	200
Overall measure of precision/variation		3 086.16	1.37%	–

On the other hand, the ratio estimate of total agricultural land area in the province based on data from the 200 sample meshes is 225 637.45 hectares. This has a much higher standard error of 2 960.24 hectares as well as a higher coefficient of variation of 1.31 percent. However, considering that the size of the first sample is much larger compared with the number of sample meshes in the second, it is expected that estimates derived from the second sample will have larger standard errors than estimates based on the first sample. As such, the total agricultural land area estimate derived from the first sample seems to be a more reliable estimate than the computed ratio estimate.

To evaluate the accuracy of agricultural land area measurements derived using only Google Map and the ALIS software, 200 meshes from the original sample were randomly selected. From this set of sampled mesh, the initial agricultural land area measurements were either verified or revised based on the researchers' observations in the field.

A scatterplot of agricultural area measurements from the second sample based on Google Map and the field survey is shown in Figure 1 below. It shows that, although, there is a linear relationship between the agricultural land area measurements from Google Map and the field survey, there are also several points wherein large differences between the two measurements are observed. A statistical test comparing data from the paired samples was then applied to determine if there are significant differences in the agricultural land area measurements derived using the two processes.

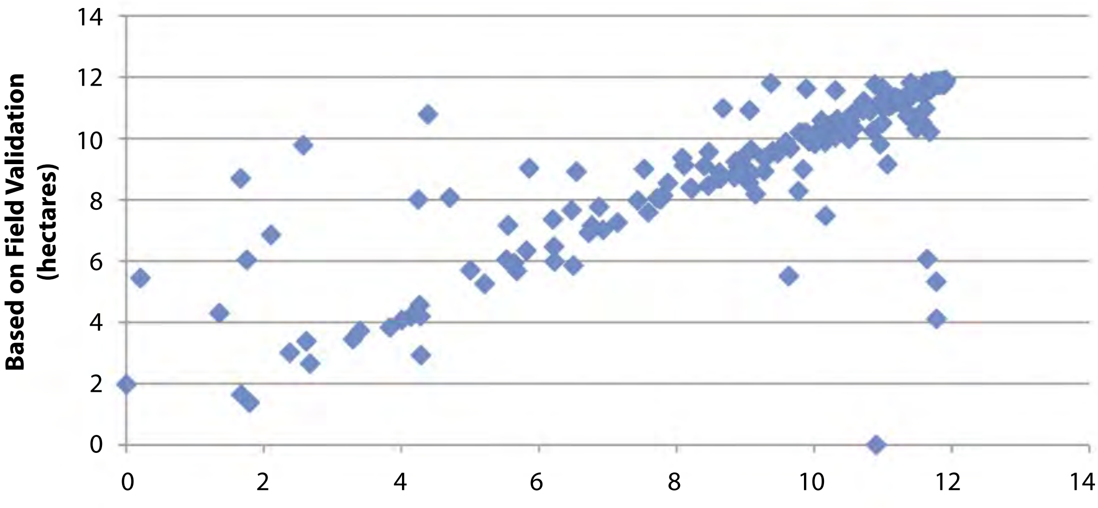


Figure 10. Scatterplot of Agricultural Lank Area Measurements from Google Maps and Field Validation

Upon testing for normality of the populations from which the samples were taken, as well as the assumption of normality of the differences in the agricultural land area measurements from the two samples, a non-parametric test, in particular, the Wilcoxon signed-rank test, was done. Results of the normality tests and the Wilcoxon signed-rank test are presented in Appendix 3 Tables 2 and 3, respectively.

Results of the test for differences in agricultural land area measurements based on Google Map and the field survey show that there are significant differences in the measurements derived using the two processes. This implies that measurements of agricultural land areas that are estimated solely based on Google Map differ from the actual agricultural land areas as validated during the field survey. On the average, agricultural land area measurements that were estimated using Google Map are lower by 0.17 hectares per mesh, as shown in Appendix 3 Table 1. In addition, the total agricultural land area estimated from Google Map differed from area measurements validated in the field by about 4 102 hectares, which is only about 2 percent lower than the field-validated total agricultural land area.

Overall, although there were differences noted in the agricultural land area measurements obtained solely using Google Map vis-à-vis land area measurements that were validated from the field, the differences may be considered acceptable. Hence, the estimate derived from the first sample can be considered a reliable estimate of the total agricultural land area in the province.

4.2 Estimates of crop planted areas

Crop planted areas in the province were also estimated for selected crops based on data from the field survey, which was concluded before the end of the third quarter 2013. Table 2 shows a summary of the estimates of areas planted with rice, maize, cassava and other crops in Nueva Ecija province. Almost 80 percent of the total agricultural land area in the province is planted with rice, with an estimated planted area of 176 445.92 hectares. Compared to available data on harvested areas from the BAS presented in Appendix 3 Table 4, the rice area harvested in the province comprises more than 87 percent of the total crop harvested areas. Total rice area harvested reached 155 275.00 hectares up to end of the third quarter of 2012, while the area harvested with maize reached 6 141.00 hectares during the same period.

Table 2. Crop Planted Area Estimates by Type of Crop, Nueva Ecija (in hectares)

Type of Crop	Value	Share (%)	Standard Error	Coefficient of Variation
Rice	176 445.92	78.09	7 015.47	3.98
Maize	333.57	0.15	225.74	67.68
Cassava	573.95	0.25	430.57	75.02
Others	48 597.03	21.51	5 833.48	12.00

Despite comparing estimated planted areas (based on the conducted field survey) with the data on harvested areas from the BAS, it is clear that there is a big difference in the figures pertaining to maize. The estimate of area planted with maize is only 333.57 hectares based on the field survey. However, with a very high coefficient of variation of 67.68 percent, the crop planted area estimate for maize may not be reliable; similarly for cassava, with a coefficient of variation of 75 percent. In addition, the high coefficients of variation of the planted area estimates for the two crops may be due to the fact that very few of the sampled meshes were planted with maize and cassava. In general, only the estimates for rice planted areas in the province can be considered reliable with a coefficient of variation of only about 4 percent.

5. Conclusion and recommendations

With the use of Google Map as applied in the ALIS, a reliable estimate of the total agricultural land area in Nueva Ecija was derived, despite some noted differences in the agricultural land area measurements from Google Map and the field survey. These differences, however, may be considered acceptable, with a difference in the estimated total agricultural land area based on Google Map of only about 2 percent from the field-validated data. As a result, there is definitely a need to enhance and improve the use of remote sensing technologies in the country in generating official agricultural statistics, specifically, agricultural land area estimates.

The software design should allow for stratified simple random sampling (SRS) of meshes so that areas planted to other crops can be better estimated. Instead of classifying meshes as agricultural vs. non agricultural, classification of meshes can be according to types of crops. This will ensure that crops are well-represented and have a better estimate of the planted areas per crop. The software should also be open to inputs from data sources other than Google Earth.

Another round of field validation may be conducted in the pilot province to further assess the level of accuracy of the agricultural land area measurements derived using Google Map by applying the same system in ALIS during another cropping season. The same system may also be applied in other areas to evaluate how effective the system is in estimating total agricultural land areas in other provinces.

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Appendix 1

Mesh classification guidelines

a. Areas considered as agricultural include:

- Areas with images of vegetation
- Areas planted with permanent crops
- Vacant lot/idle lands (burnt surrounding areas should be considered in classifying the area as agricultural); Such areas should be validated in the field survey. This means the information will only be reflected in the meshes included in the second sample.

b. Areas not included as agricultural include:

- Burnt areas in the forest
- Household gardens
- Areas on the map covered by clouds

c. Check with regional/provincial officers in cases when there are areas on the maps that are difficult to classify.

Appendix 2

Table 1. Team and mesh assignments of BAS personnel

Team No.	Members	Mesh Assignment	Mesh Location
1	Rodrigo N. Labuguen (CO)		
	Jessica Astovesta (CO)		
	Girlie de Guzman (OC)		
2	Dionisio de Vera (CO)		
	Mary Ann Alcachupas (CO)		
	Jonabel Yu (OC)		
3	Sharon Rose Estrella (CO)		
	Bernabe Mauyao (OC)		
	Rommel Payawal (OC)		
4	Necita De Guzman (CO)		
	Imelda Ornos (CO)		
	Priscillano Jove, Jr. (OC)		
5	Nelson Lagniton (CO)		
	Damaso del Rosario (CO)		
	Isabelita Gamboa (OC)		
6	Juliet Perez (CO)		
	Rey Versula (OC)		
	Aurea Bernardo (OC)		

CO – Central Office
OC – Operation Center

Appendix 3

Statistical tables

Table 1. Agricultural land area measurements summary statistics

Indicator	First Sample (Google Map)	Second Sample		
		Google Map	Field Survey	Difference, d_i
Sample size	4 928	200	200	200
Mean	9.22	9.24	9.41	-0.17
Sum	221 542.21	221 848.32	225 949.27	-4 100.95
Standard deviation	6.31	31.98	28.69	18.90
Variance	39.88	1 022.71	823.33	357.23

Table 2. Test for Normality

Measurement Process	Test Statistic, W*	p-Value
ALIS using Google Maps	0.827184	<0.0001
Field Survey	0.846084	<0.0001
Difference, d_i	0.626106	<0.0001

* Refers to the Shapiro-Wilk test statistic

Table 3. Test for Differences in Agricultural Land Area Measurements

Test	Test Statistic, S*	p-Value
Signed Rank	-2516.5	<.0001

* Refers to the Wilcoxon signed rank test statistic

Table 4. Area Harvested by Crop Type and Period, Nueva Ecija, 2012

Type of Crop	Period						Annual	Share (%)
	Quarter 1	Quarter 2	Semester 1	Quarter 3	Quarter 4	Semester 2		
Palay (Rice)	23 720.0	103 925.0	127 645.0	27 630.0	148 914.0	176 544.0	304 189.0	87.6
Corn	2 091.0	1 818.0	3 909.0	2 232.0	262.0	2 494.0	6 403.0	1.8
Cassava	…	…	…	…	…	…	84.0	0.0
Others	…	…	…	…	…	…	36 733.5	10.6
Total	**…**	**…**	**…**	**…**	**…**	**…**	**347 409.5**	**100.0**

Source: Bureau of Agricultural Statistics website, accessed 28 September 2013.
http://countrystat.bas.gov.ph/?cont=10&pageid=1&ma=O80LUAHC
http://countrystat.bas.gov.ph/?cont=10&pageid=1&ma=P00LUAHO

Rice crop monitoring in Thailand using field server and satellite remote sensing

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ABSTRACT

Rice is the staple food crop consumed by more than 50 percent of the world population. It supplies more calorie intake in developing countries than any other food in the world. Thailand is one of the top rice exporters in the world. Rice is the most important economic crop in Thailand with 3.7 million rice farm households. It is a major income source and nutrient for rural families. Accurate monitoring and mapping of the rice crop areas are critical for regional rice cropping/water managements and estimates of rice yield (Bridhikitti and Overcamp 2012). Remote sensing does seem to be the most reliable measurement tool for accurate rice crop monitoring over large areas. This article presents the research activities to assess and monitor rice paddy in Thailand using field server and satellite remote sensing.

1. Introduction

Rice is the staple food of the Thai people. It is rich in nutritional value and very important in Thai culture. Rice also plays an important role in the Thai economy because Thailand has high volume of exports. Thai rice is known around the world, especially "jasmine rice", a breed of long grain rice known for its taste and fragrance. Its crop cycle is 5-6 months; most are planted in the rainy season. That is called a single crop cycle per year. Since Thailand has two patterns of rice cultivation, namely, season rice and out of season rice, the latter has shorter growing period. Rice can be grown throughout the country, depending on the availability of water. Therefore, areas with irrigation have higher potential.

Change detection and classification of agricultural produce can be achieved by the use of remote sensing, which is the monitoring of the situation of the agricultural areas with a large coverage at once. It is possible to distinguish different crops on the field. It can also be used to evaluate agricultural production as well. Under the principles of remote sensing systems the use of reflection of the wave and the energy released by the object can be used for such application. The data appears as a digital number, derived from sensors mounted on aircraft or on satellites. Each orbiting track covers a wide area. The data in the form of signal spectrum, when analyzed and interpreted in the form of a map, can be used as numerical data, table or chart.

On the other hand, *in situ* data is necessary for calibration and validation of the product derived from satellite images. Collecting the *in situ* data is very costly and time consuming. Therefore, field server (FS) seems to answer the difficulties that we face. FS is an Internet Field Observation Robot that consists of a set of multiple sensors, a web server, an Internet Protocol (IP) camera, as well as wireless interfaces. It is designed to provide an outdoor solution for environment monitoring.

This study aims to present recent development in rice monitoring in Thailand using field server and satellite remote sensing. The rice phenology with NDVI from 16 day MODIS data and rice crop height detection are shown here. We show the potential of using field server to measure rice crop height based on digital image processing techniques. A digital camera in field server provides photos of the rice crop field. Rice crop height can be indirectly measured by measuring the height of a marker bar. The benefits of the method are: reduced manual work; lower cost; and fast computing and real time assessment. The results of the study are useful to the development of crop management systems, setting of Thai rice prices and insurance systems, which will affect planning and rice-growing farmers, ultimately leading to better living standards for the farmers.

2. Study area

Since rice farming in Thailand is spread all over the country, this study chose an area in the Central Region of the country (shown in Figure 1) as a study area which has a good irrigation system and several major rivers to support agriculture. This area is in the river plains interspersed with hills, and is suited to agricultural activities. The study area is located on the tropical grasslands, near the equator, with moderate rainfall, and occasional drought. The rainy season is during May to October, when there is enough water to grow rice. In the dry season, irrigation systems support cultivation in the area (Boschetti *et al*. 2009; Julien and Sobrino 2010). Regarding the climate in the area, the lower part of the area is wetter than the upper part.

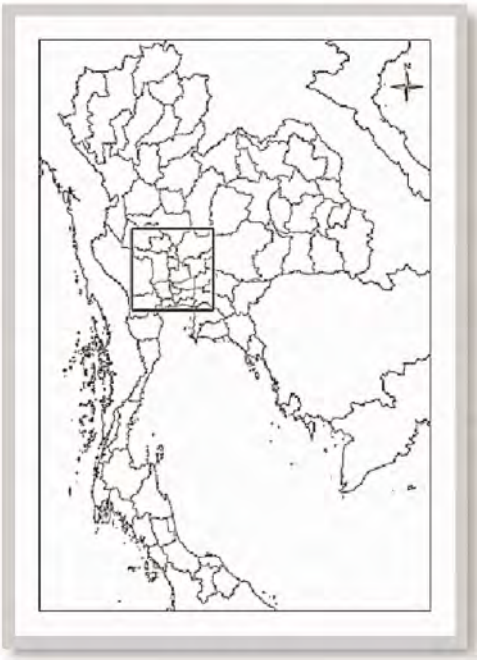

Figure 1. Study area

3. Satellite monitoring rice growth

In this study, Terra MOD13Q1 (Vegetation Indices) was used, which calculates the vegetation index of a 16-day cycle at a resolution of 250 meters by using index difference vegetation and NDVI. The imagery covered an eleven-year time series, from 2000 to 2010 to fit the phenology of the plant cover and in particular the area planted with rice. Time series data is the normalized difference vegetation index (NDVI) used in the analysis area (Boschetti *et al*. 2009). The MOD13Q1 is a tile product. "MODIS Reprojection Tool 4.1" is a tool to mosaic tile product and re-project into Universal Transverse Mercator (UTM) Thailand in zone 47-48. This tool can extract NDVI bands for MODIS data for analysis.

The MODIS time-series by Normalized Difference Vegetation Index (NDVI) data (16 days composite) has noise from inclement weather and clouds to affect the reflection of false light. The NDVI time series data of that pixel will have signal abnormalities. It is not accurate and affects the data analysis. A solution is to use the time series to filter the noise signal (Julien and Sobrino 2010) to accurately obtain the time series of the NDVI by the phenology of vegetation covering the area.

After filtering the signal with a Savitzky-Golay filter (Savitzky and Golay 1964) the signal of the time-series is smoother. The acquired image data goes through a separate processing to demonstrate the characteristics of the different areas in the study area by means of the image data. The rest of the information is needed to divide the area by the analysis component (PCA), and is necessary to divide by the area of the signal in the same manner and to identify areas with a colour space that can be divided into groups.

The results are shown in Figure 2, which notes that each area has a signal that varies according to land use by agricultural activities. The area covers farm, park, hilly area, water, etc. all exhibiting different signals that are expressed in different forms. This study focuses on the area planted with rice by single crop planting and multi crop pattern where the signal varies. When the area is planted with multi crops, it showed different patterns.

4. Field server

Field server has been developed (Fukatsu and Hirafuji 2005; Fukatsu *et al*. 2006) to monitor environment parameters. Field server provides various sensors, cameras, communication and control units. A digital camera is a sensor that converts an optical image into an electronic signal. Communication units are used in transmission of sensor data and command data between field server and computer server. Control units are used to command the system of the field server. The power supply unit supplies electric power to electrical loads. A control unit was programmed to manage sensors and cameras, including the system. When the sensor measures environment, observation data is acquired by the stored unit and transferred to the computer server. Data is collected in the computer server and managed to display on a webpage. Users can access data through a web browser via the internet. The data is separated into two display types: 1) log data for common sensor; and 2) image series for camera sensor.

The field server technology is useful to monitor environments or activities through sensors and cameras. Users can collect data such as rain, humidity, wind, temperature, soil moisture, etc. to support planning and management. The field server has a sensor that measures air temperature and another that measures air humidity. Both sensors are used in combination to reduce cost. A rain gauge tipping-bucket is an instrument to gather and measure the amount of liquid precipitation over a set period of time. An anemometer is a device for measuring wind speed, and is a common weather station instrument. The device is used to describe any airspeed measurement instrument used in meteorology or aerodynamics. Anemometers can be divided into two classes: those that measure the wind's speed, and those that measure the wind's pressure. A pyranometer is used to measure broadband solar irradiance on a planar surface and is designed to measure the solar radiation flux density. A soil moisture sensor measures the amount of moisture found in the soil. It is most often used for agriculture. This sensor can measure moisture right near the roots. DSLR (Digital single-lens reflex) Cameras provide RGB (Red, Green, Blue) and NIR (Near infrared) images.

The field server shown in Figure 3 is installed for monitoring a rice crop field. As a sensor of the field server, a digital camera is used to provide photos of the rice crop field. The height of rice crop can be measured from the photos. Since rice height is hard to directly measure because the stalk is quite small and there are so many rice plants in any particular field, rice crop height can be indirectly measured by measuring the height of a marker bar. The images comprise the rice plants and the marker bar. The marker is focused and detected for measuring while other things such as rice field, soil, cloud, and sky are defined as background. The proposed method gives an average height of the rice crop in the field. Figure 3 shows field server at a rice crop field in Suphan Buri Province, Thailand. The product image of this field server is also shown in Figure 4.

The marker is detected for indirect measuring of rice crop height. For digital image processing techniques, the feature selection method is used to remove redundant features. The feature extraction module extracts more differential features between the marker bar and the others. Image segmentation is applied to separate the marker bar and the others. The marker bar is detected and compared with the initial marker bar to measure the rice crop height. The flowchart of this method is shown in Figure 4 and the details are described in four topics of feature selection, feature extraction, image segmentation and measuring (Gonzalas and Woods 2008).

The rice crop height can be reliably measured by human evaluation of the image. Therefore, the results of this method are set as the reference and compared with the results of our proposed method. Relative error index is selected to verify the accuracy of our experimental results. The experimental results are shown in Figure 5. For a single crop per year, the corresponding NDVI signature show two peaks a year, but the smaller peak of NDVI represents the grass growth at the start of the rainy season (or natural re-growth on residual moisture). For two or more crops per year, farmers start planting whenever water is available and vary the number of crops per year, and thus it is very difficult to define an exact crop calendar of this area. In this area, rice is grown from one to three times per year.

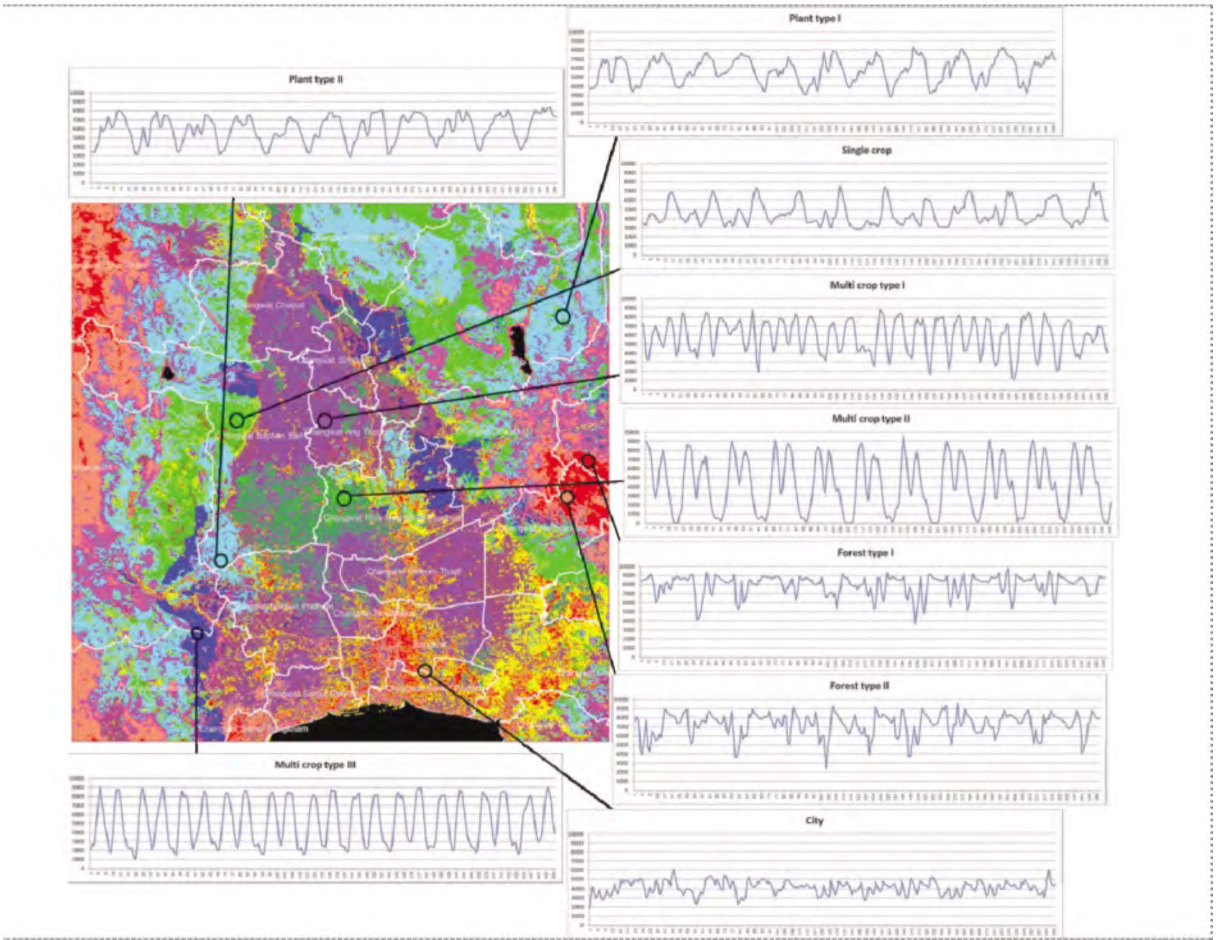

Figure 2. Area grouping based on NDVI

Figure 3. The field server at a rice crop field in Suphan Buri Province, Thailand

Figure 4. Photo showing rice crop height monitoring at a rice crop field in Suphan Buri Province, Thailand

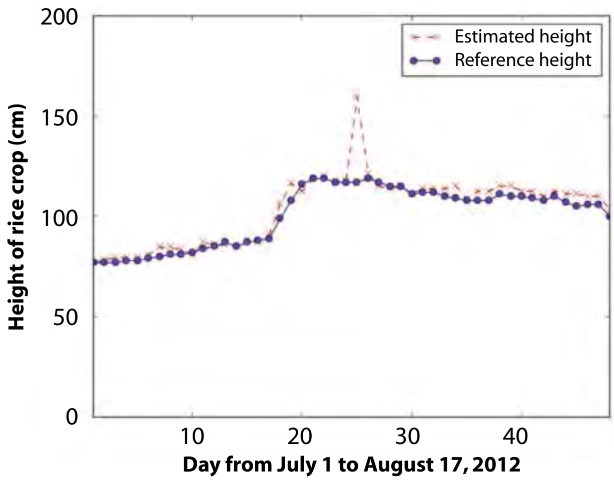

Figure 5. Rice crop height series from date of July 1 to August 17, 2012 using automatic height detection algorithm

5. Conclusion

This study aims to present recent developments of rice monitoring in Thailand using field server and Terra MODIS images. The results of research by NDVI time series indicate that the areas in the study area have some form of agricultural activity with a lot of variety. The study area covers an area around the farm. Farm land, park, hilly area, water, etc. all exhibit different signals that are expressed in different forms. This study focuses on an area planted with rice by single crop planting and multi crop pattern where the signal varies. When the area is planted with multi crop, it showed different patterns that indicate two crops per year, two to three crops per year and three crops per year depending on the natural topography of the multi crop planting area in the river basin. This paper also presents a method for measuring rice crop height by using field server image processing techniques. The proposed method can measure rice crop height effectively. This method can be adapted for the feature of the marker bar which depends on designation. The advantages of the method are four-fold: replacing human evaluation, lower cost, speedy operation and real time system.

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A new method to estimate rice crop production and outlook using Earth Observation satellite data

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Key words: Synthetic Aperture Radar (SAR), ScanSAR, AFSIS, GEOGLAM, Asia Rice crop

ABSTRACT

From 2011 to 2012, The Rice Crop Workgroup; a collaborative project of the Japan Aerospace Exploration Agency (JAXA), the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand, and the Remote Sensing Technology Center of Japan (RESTEC) developed a method to estimate rice crop area and production using space-based Synthetic Aperture Radar (SAR). RESTEC developed the software (International Asian Harvest Monitoring System for Rice – INAHOR) on behalf of JAXA, under contract to JAXA. INAHOR will be applied to Vietnamese and Indonesian sites under their country's and JAXA's joint Asia-Pacific Regional Space Agency Forum (APRSAF) projects and the GEOGLAM Asian rice crop monitoring team activity (Asia-RiCE). Additionally, a JAxa's Satellite based Monitoring Network system (JASMIN) was implemented to support rice crop outlook information provision to FAO AMIS as part of Asia-RiCE GEOGLAM activities. This was done in cooperation with the ASEAN Food Security Information System (AFSIS) project under contract to JAXA.

1. Background

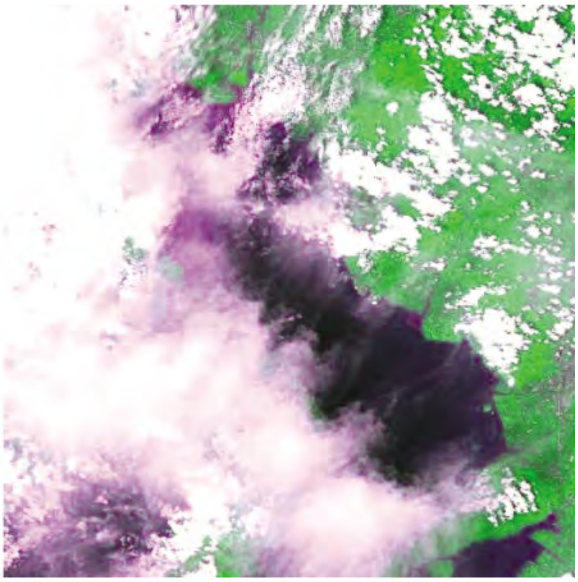
The G20 Agriculture Ministers agreed on an "Action Plan on food price volatility and agriculture" during their first meeting in Paris, 22-23 June 2011. The action plan was then submitted to their Leaders at a Summit in November 2011. In order to improve crop production projections and weather forecasting, the use of modern tools was promoted, in particular remote sensing. The Group on Earth Observations (GEO) was directed to develop an international voluntary network for agricultural production monitoring. The GEO Global Agricultural Monitoring initiative (GEOGLAM) serves as a useful input for the Food and Agriculture Organization of the United Nations (FAO) Agricultural Market Information System (AMIS), which aims to the provide more accurate crop forecast data of four type of commodity crops – wheat, maize, rice, and soybeans. Since rice is the main commodity crop in Asia, the Japan Aerospace Exploration Agency (JAXA) proposes and leads the Asian Rice Crop Estimation & Monitoring project (Asia-RiCE), which focuses on leveraging space technology to represent rice crops in GEOGLAM. Asia-RiCE is a collaborative effort between a number of Asian organizations in countries including India, Indonesia, Thailand, and Viet Nam.

RESTEC provides the technical and administrative support for JAXA's lead role in Asia-RiCE. In 2009 and 2010, a system was developed for the Ministry of Agriculture, Forestry and Fisheries (MAFF) to estimate rice crop acreage using GIS and space-based remote sensing data. During 2011and 2012, the JAXA-GISTDA Rice Crop workgroup in collaboration with RESTEC developed software to estimate rice crop acreage and production using space-based Synthetic Aperture Radar (SAR) from the ALOS and THEOS series of satellites. The software, named INAHOR (INternational Asian Harvest mOnitoring system for Rice) will be applied to Viet Nam and Indonesia under a Space Application for Environment (SAFE) prototyping project of the Asia-Pacific Regional Space Agency Forum (APRSAF). This prototyping result will also be useful for the GEOGLAM Asia rice crop team activity, Asia-RiCE. Additionally, a JAxa's Satellite based Monitoring Network system (JASMIN) is implemented to support rice crop outlook information provision to FAO AMIS as part of Asia-RiCE GEOGLAM activities. This was done in cooperation with the ASEAN Food Security Information System (AFSIS) project in 2013.

This paper discusses the development of this space-based remote sensing application for rice crop monitoring in Asia.

2. Proposed methodology

Because Earth observation satellites can observe large spatial extents at high temporal frequency and in high quality for reasonable cost, they are a very powerful tool for agricultural monitoring at national and provincial levels. For agricultural monitoring of crops including corn, wheat, and soybean, time series of optical data from missions such as Landsat are commonly used to estimate crop area and production very efficiently and effectively. However, Asian rice crops are generally grown during the rainy season (monsoon season), and cloudy and rainy weather conditions cause problems in estimating paddy area and rice production using optical sensors. Space-based Synthetic Aperture Radar (SAR) is a useful tool for rice crop monitoring, as the microwave frequencies used can penetrate cloud cover/rain to give accurate information of the Earth's surface. SAR is used to complement optical sensor data to estimate rice crop area and production in Asia. Figure 2.1 shows images observed simultaneously by ALOS's optical AVNIR-2 sensor and SAR PALSAR instrument. Although clouds in the AVNIR-2 image obscure the ground, it is clearly captured in the PALSAR image.



©JAXA

ALOS AVNIR-2 (Optical Sensor)

©METI/JAXA

ALOS PALSAR (SAR)

Figure 2.1. Images observed simultaneously by ALOS

The basic approach to estimate paddy area using SAR is shown in Figure 2.2. SAR instruments emit a microwave signal and receive the echo (the microwave backscattered signal) from the ground. When newly planted, rice weakly backscatters the signal to the satellite because of minimal polarisation (specular reflection), and the SAR data image becomes dark (low count value). At a well-grown stage, the microwave backscatter becomes strongly polarised, and the brightness of the image increases. Using the well-established relationship between backscatter and crop growth stage, we can estimate the rice crop area.

Figure 2.3 is a flow chart that demonstrates the process of using INAHOR to estimate rice crop area with SAR data. Firstly, the SAR images are opened, selecting one for the planting season and another for the well-growing season. Next, two threshold values are set to differentiate flooding areas and well-grown areas. Finally, following noise reduction, an estimate of the rice crop area is made. Flooding and well-grown areas are classified by image analysis processing. If the result is poor, a change of threshold values is made and the analysis is repeated. The rice crop production is calculated using this rice crop area and values for yield per unit, which is derived from statistic information or field surveys.

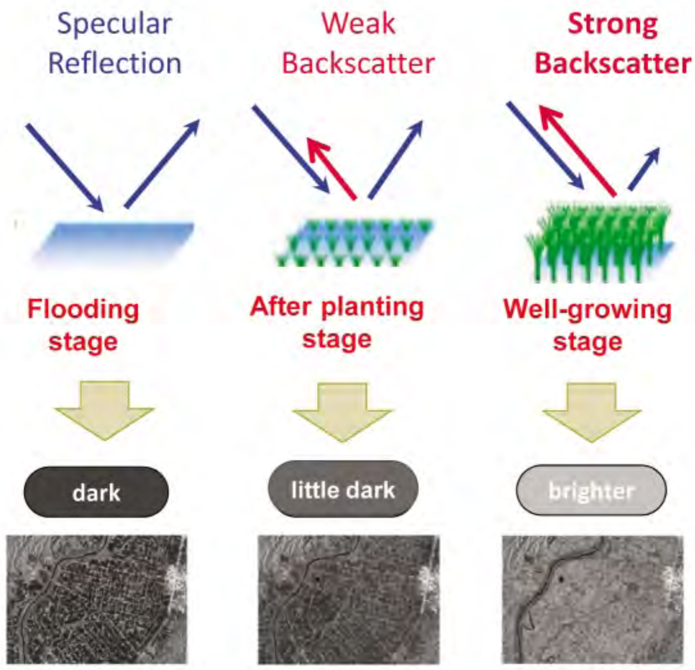


Figure 2.2. Basic approach to estimate paddy area using SAR

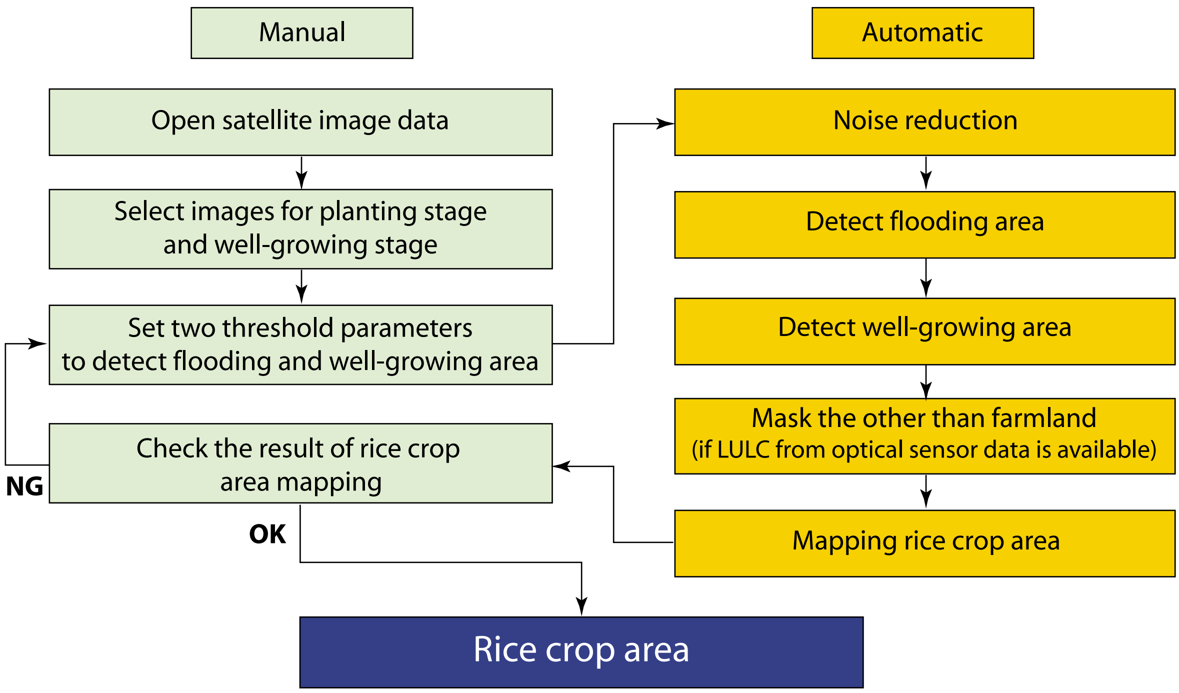


Figure 2.3. Flow chart that demonstrates the process of using INAHOR

3. Results

This methodology was applied during the JAXA-GISTDA cooperative project in 2011 to estimate the acreage and production of rainy-season rice crops at Khon Kaen Province in Thailand. Khon Kaen is located in the northeastern part of Thailand, and most of the rice fields are rain fed. About 200 field surveys were conducted for validation purposes. Crop yields (production per area) were measured by harvesting approximately 1 square of the crop at its harvesting stage. The field surveys also revealed that the local crop calendar is as follows: direct seeding from June to July; transplanting from July to August; and harvesting from November to December. The satellite data used was Canadian RADARSAT-2 data provided by GISTDA. The multi-look fine mode (HH polarization) was used, which offers 8 m spatial resolution, and a 50 km observation swath width. The results of the analysis are shown in Figure 3.1. Imaging data from 20 June, 14 July, and 7 August were used for the planting stage and data was observed on 7 August and 31 August for the well-grown stage. Urban, water, and forested areas were masked-out using land cover classification maps derived from ALOS AVNIR-2. The validation results using data from the field survey are shown in Table 3.1. The accuracy of estimated rice crop acreage was more than 90 percent of the field survey value. Conversely, the accuracy of estimated productions was about 80 percent of the field survey value. This is because the variation in the yield of direct seeding fields was large at the verification site, and varied substantially from the statistical information which was used to estimate the production.

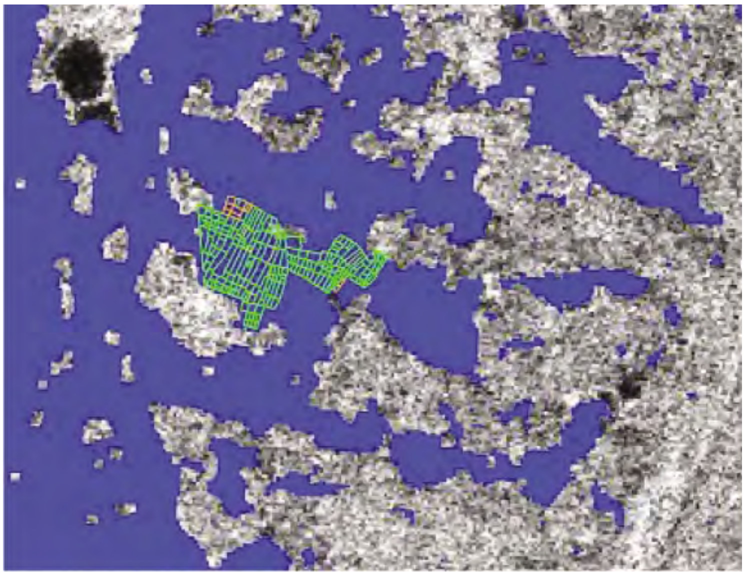


Figure 3.1. Result of the analysis at study site in Khon kane in 2011

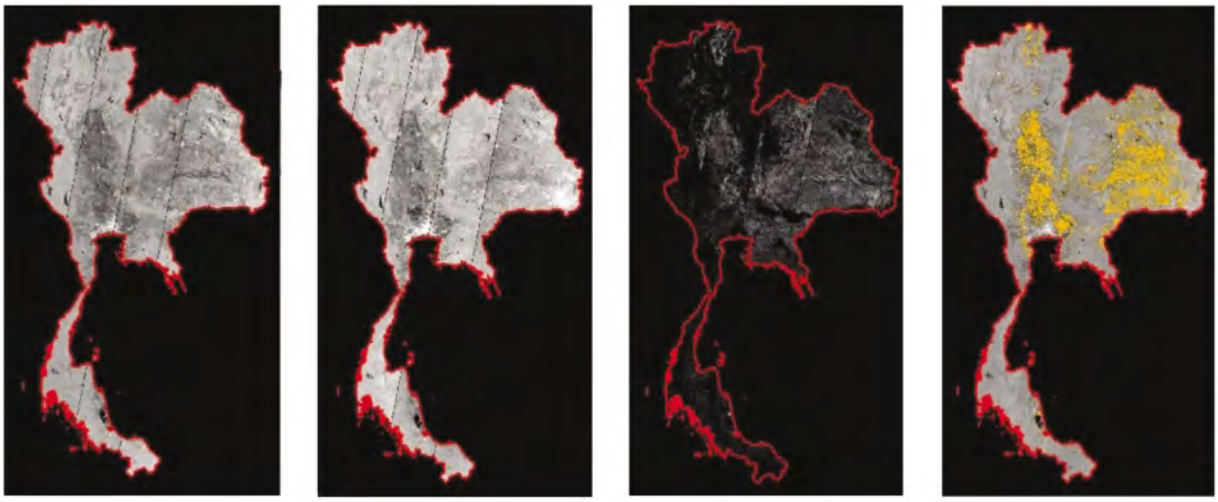
Table 3.1. Validation results using data from the field survey in Khon kaen in 2011

	Acreage [m^2]	Yield [g/m^2]	Production [ton]
Estimation value	164 405.99	(203.96)*1	33.53
Validation value	166 766.39	2.47–750.08	40.96
Accuracy of estimation	98.58%	–	81.87%

*1 The statistic information was used to estimate the production.

In the second year of the JAXA-GISTDA collaboration in 2012, the methodology of estimating rainy season rice crop acreage using SAR was updated and applied at the Suphan Buri Province in Thailand. Suphan Buri is located in the central region of Thailand, and features mostly irrigated rice paddys.

In addition to fine-mode (high-resolution) SAR, wide-mode SAR data (ScanSAR) was used to make wall-to-wall estimates of the acreage and production of Thailand's rainy season rice crops. The satellite data used was from ALOS PALSAR and was provided by JAXA. ScanSAR mode (HH polarization) was used, which provides a 100 m spatial resolution, and a 350 km observation swath width. Although ScanSAR data is coarser, monthly updates for the entirety of Thailand can be achieved. And, it is useful to estimate rice crop area at the provincial level. The results of the analysis using ScanSAR data is shown in Figure 3.2. Imagery collected in 2009 was used, with the planting stage defined as April to August, and the well-grown stage was taken to be August to November. Non-vegetation area and high altitude land were masked-out using MODIS NDVI and SRTM DSM. By comparing with statistical information provided by Thailand's Office of Agricultural Economics (AOE), an accuracy of more than 70 percent was confirmed in 76 provinces. In the future, it is suggested that the methodology be improved by conducting field surveys in other areas that have different local situations than Khon Kaen or Suphan Buri.



Minimum value image for planning stage | Maximum value image for well-growing stage | Difference image between planting stage and well-growing stage | Estimated area of rice crop

© METI/JAXA

Figure 3.2. Results of the analysis using ScanSAR

Finally, the software for estimating rice crop acreage and production called INAHOR was developed using the above methodology. INAHOR will be applied to Vietnamese and Indonesian sites under JAXA and the countries' joint projects as part of the APRSAF SAFE prototyping and the GEOGLAM Asian rice crop team activity (Asia-RiCE).

In the future the aim is to develop the system for use in GEOGLAM/Asia-RiCE. Asia-RiCE was launched by JAXA after the Agricultural Ministers' 2011 G20 meeting in Paris, France, during which it was decided to launch AMIS and GEOGLAM. The Asia-RiCE team aims to start operational rice crop monitoring in Asia from 2017, and is currently in the Phase 1 stage (proof of concept). In Phase 1, four 100 km x 100 km technical demonstration sites were selected in Indonesia, Thailand, and Viet Nam (North and South). These sites are being used to verify the rice crop monitoring methodology using statistical information, ground (*in situ*) observations, computer modelling, SAR, and other space-based observation data. The results of a study on Southern Viet Nam's An Giang province Asia-RiCE Technical Demonstration Site (TDS) that used the 2007 wet season rice crop ALOS PALSAR data is shown in Figure 3.3.

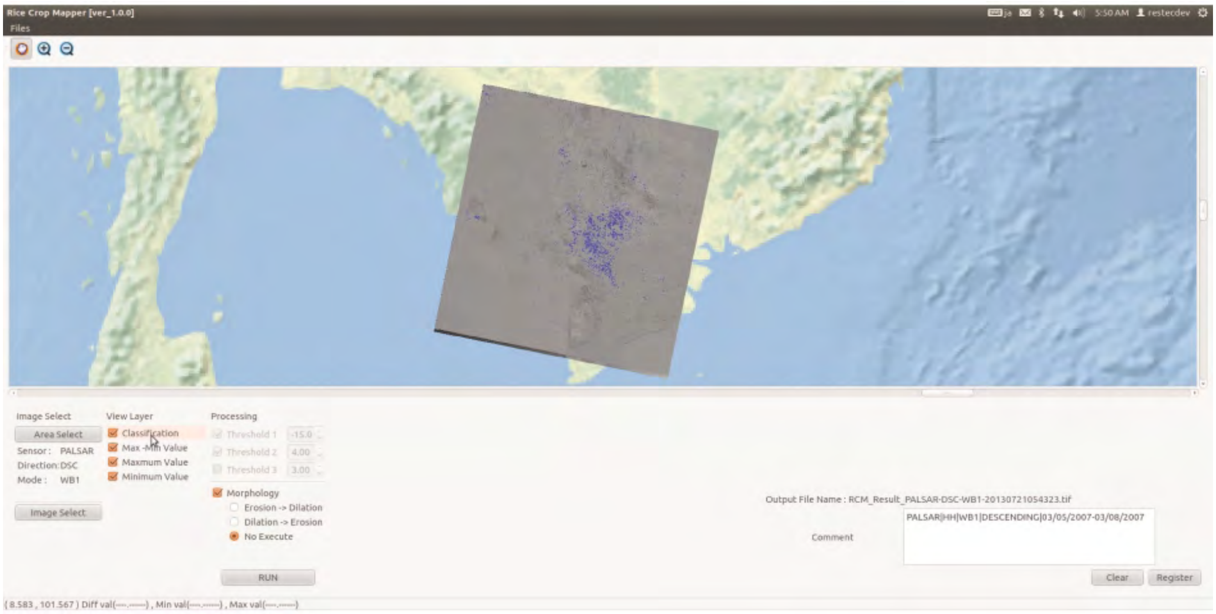


Figure 3.3. Example of INAHOR at Southern Viet Nam's An Giang province

Asia-RiCE, led by JAXA, has also started to provide rice crop outlooks in Thailand, Viet Nam and Indonesia for FAO AMIS. The work-flow for making these rice crop outlooks is shown in Figure 3.4. JAXA provides satellite weather information to statistical experts in each country in cooperation with AFSIS through the web system called JASMIN. The statistics officers make rice crop outlook reports using ground-based observation data, field surveys, statistical information and JASMIN. AFSIS compiles the three countries' outlook text and provides it to the Asia-RiCE team for review. During the review, some additional outlook information derived from monthly satellite data is added. JAXA then posts the outlook to GEOGLAM through The University of Maryland (UMD) GEOGLAM outlook homepage. GEOGLAM also compiles monthly outlook reports for corn, wheat, and soybean. AMIS uses this information to publish their "Market Monitor".

Figure 3.4. Work-flow for making rice crop outlooks

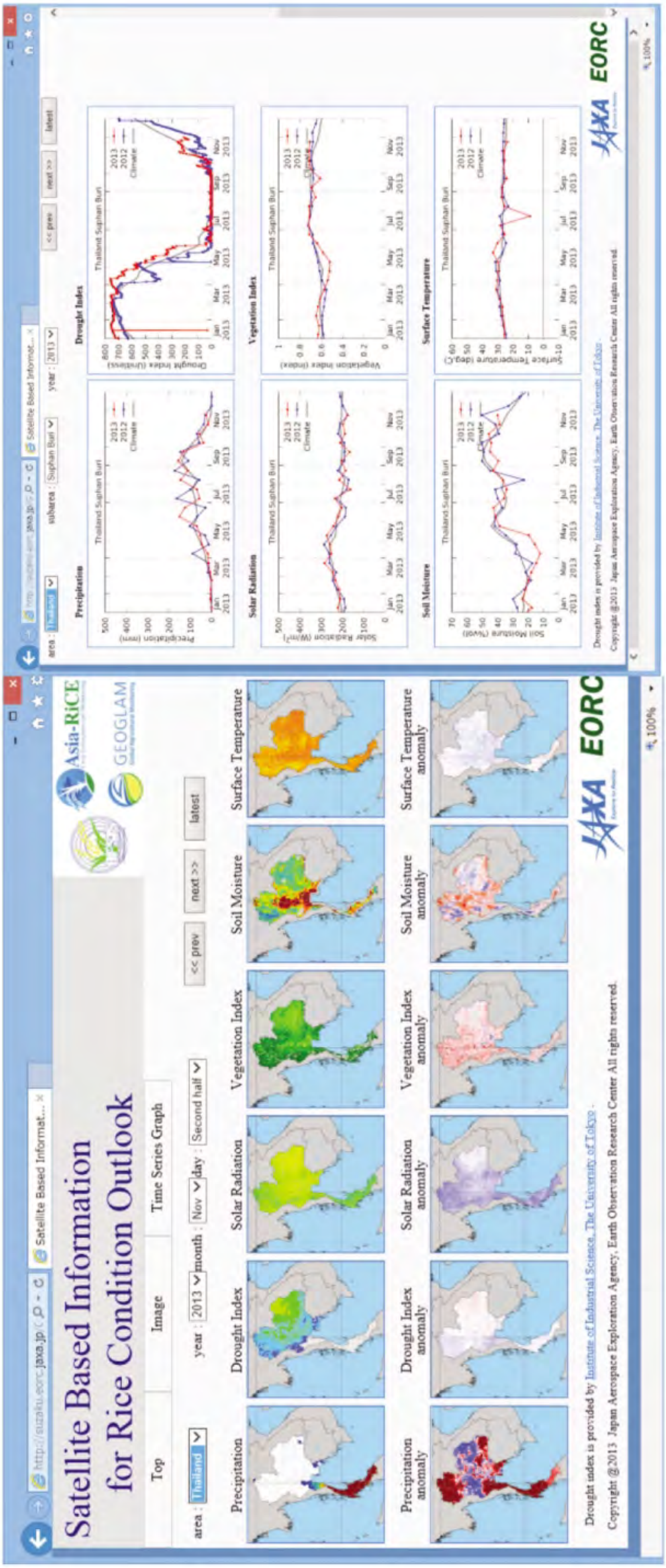


Figure 3.5. JASMIN user interface

RESTEC developed JASMIN to provide satellite weather information to statistical experts. The JASMIN user interface is shown in Figure 3.5. Sample information provided by JASMIN is shown in Table 3.2. JASMIN displays information in maps and graphs, and includes information on current conditions and anomalies (deviations from past normal years) such as Precipitation, Solar Radiation, Land Surface Temperature, Soil Moisture, Keetch-Byram Drought Index (KBDI) (developed by The University of Tokyo) and Normalized Difference Vegetation Index (NDVI). Data is updated twice a month.

Table 3.2. Information provided by JASMIN

Parameters	Interval	Spatial Resolution	Data Period (anomaly calc.)	Satellite Data Source
Precipitation	Cumulative (15-day)	10 km	2002–(2002–2012)	GSMaP (GCOM-W1, TRMM, MTSAT etc.)
Solar Radiation	15-day Average	5 km	2007–(2007–2012)	MODIS
Land Surface Temperature	15-day Average	5 km	2002–(2002–2012)	MODIS
Soil Moisture	15-day Average	50 km	2009–(2002–2012)	AMSR-E, WINDSAT
Drought Index	15^{th} /31[30]th day of month	10 km	2003–(2003–2012)	GSMaP, MTSAT
Vegetation Index	15^{th} /31[30]th day of month	5 km	2002–(2009–2012)	MODIS

4. Conclusions

RESTEC developed INAHOR and JASMIN under contract to JAXA. INAHOR is software that is used to estimate rice crop acreage and production using SAR data. JASMIN is a web-based system that provides satellite agricultural weather information to statistical experts for the purpose of making crop outlooks. JAXA and RESTEC are working to verify their methods of rice crop monitoring using EO satellite data for GEOGLAM/Asia-RiCE.

To improve the accuracy of estimation, studies are being undertaken to better distinguish rice from other crops by analysing biomass in the well-grown stage, and analysing the period from planting to harvest, paying attention to the characteristics of cross polarization and analysing complex images with full polarizations. To estimate rice crop production with high accuracy, the yield for each field type is required. Studies are underway to get yield from SAR data by using a correlation between biomass and the SAR backscatter. In addition, we also preparing to apply new SAR sources such as ALOS-2 and Sentinel-1. ScanSAR modes will be able to provide national-level statistical information of rice crop area and production in Asia.

Rice crop outlooks using the satellite weather information system JASMIN are not yet mature and it is expected that more knowledge will be accumulated. In the future, JASMIN will be expanded to support FAO AMIS outlook reporting for other ASEAN countries in cooperation with AFSIS.

Crop planting and type proportion method for crop acreage estimation of complex agricultural landscapes

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ABSTRACT

This study presents a crop planting and type proportion (CPTP) method for crop acreage estimation of complex and diverse agricultural landscapes. CPTP has three major components: (1) Crop planting proportion (CPP), estimated with wide-swath satellite remote sensing data to completely cover the monitoring area by segmenting cropped and non-cropped areas through unsupervised classification. (2) Crop type proportion (CTP), estimated by transect sampling and a special GPS-Video-GIS instrument (GVG) and a visual interpretation of crop type proportion in collected pictures for different strata. (3) Multiplication of CPP and CTP with arable land area at the strata level, summed to the province and national level. Validation has been done with *in situ* data for different agricultural landscapes over China. Both CPP estimation with remote sensing data and CTP estimation through ground survey have a high accuracy with average relative error (RE) and root mean square error (RMSE) equal to 1.42% and 1.67% for CPP and to 2.63% and 2.25% for CTP. The RE for crop acreage estimation equals to 4.09%. The CPTP method thus has a high accuracy, yields timely information at low costs, and is robust and provides objective results. The study concludes that the CPTP method can be used for large area crop acreage estimation of complex agriculture landscapes.

1. Introduction

Reliable and timely forecasting or estimation of crop production is critical for national food security as it is a requirement for decision making on economic policies and price optimization (Thornton et al., 1997; Wang et al., 2010a,b). Recently, arable land in China is decreasing, due to rapid urbanization and industrialization (Liu et al., 2005a,b; Chen, 2007; Liu and Liu, 2009), and enthusiasm of cereal production get lower due to the less income. Crop acreages are crucial for crop production forecasting or estimation besides crop yield. Thus it is essential to know the crop acreage timely. However, it is a challenge to offer timely, accurate crop acreage information in China due to the huge producing area, the complex agricultural landscapes with the variety of cropping systems, the diversification of crop types, the very small field sizes and the particular management practices (Wu and Li, 2004).

Various types of remote sensing data are available to estimate crop acreage at regional scales using digital classification methods, such as optical data with high spatial resolution (Castillejo-González et al., 2009; Oza et al., 2008), medium spatial resolution (Badhwar, 1984; Dutta et al., 1994; Yadav et al., 2002; Chang et al., 2007), and radar data (Bouman and Uenk, 1992; Chakraborty and Panigrahy, 2000; McNairn et al., 2009). However, Pixels in remote sensing data do not always correspond to a single crop type or field. Mixed pixels have a serious impact on crop classification accuracy in agriculture regions with small crop fields. Therefore, crop classification based on remote sensing data without a solid ground survey is not sufficient for estimating crop acreage.

Remote sensing based sampling methods have been shown good solutions for large area crop acreage monitoring systems (Macdonald and Hall, 1980; Cecil and Charles, 1984; Taylor et al., 1997; Tsiligirides, 1998; Sushil, 2001; Wu and Li, 2004; Gallego and Bamps, 2008; NASS of the USDA, 2009b). Methods integrating area sampling frames and remote sensing technique should also be considered to resolve the estimation of crop acreage in China. Yet, several obstacles must be removed. The small field size of cropland requires remote sensing data with spatial resolution finer than 10 m for accurate crop identification, especially in southern China. It is un-affordable and impossible to cover the major grain producing regions with such high resolution data. The policy of the household contracting responsibility system introduced in 1978 has given more freedom of crop planting to farmers. For food diversification purposes, a single family always plants more than 3 crops and in extreme cases even more than 10 crops, to obtain a sufficient variety of food. Yet this policy leads to extra complexity in the agricultural landscape, especially in the summer and autumn seasons

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Satellite remote sensing and GIS-based crops forecasting & estimation system in Pakistan

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Key words: Satellite Remote Sensing, Crops Monitoring, Area, yield modeling, Pakistan

ABSTRACT

Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), the Space Agency of Pakistan, started developing crop area estimation procedures and crop yield models, based on the application of satellite remote sensing, GIS technology, agronomy, agro-meteorology, statistics and other allied disciplines. Conventionally, the crops area estimation system is based on Village Master Sampling (VMS) from the revenue department developed in the late 1970s by the Federal Bureau of Statistics, Pakistan. A satellite-based crops monitoring system in Pakistan has been developed to forecast and estimate crops statistics of major crops, which include wheat, rice, cotton, sugarcane, maize and potato since 2005. Crops area estimates are based on two approaches: 1) satellite data supervised classification; and 2) the area frame sampling system. Overall, classification accuracy ranged from 85-95 percent.

Yield modeling is based on the FAO approach of yield relationship with predictor variables. Crop yield forecasting and estimation cover another important dimension of crops statistics, being mostly of a qualitative nature. SPOT Vegetation data is the main yield predicting variable in all calibrated models. All major crops models including wheat, cotton, rice, sugarcane and maize were calibrated for yield forecasting during initial to peak growth seasons and estimated near harvest time. A selection criterion was the R^2 value (Co-efficient of determination) of 0.8 or more. Satellite data-based crops area and yield estimation were compiled and compared later with government official statistics. The main advantage of the SUPARCO satellite-based crops system is timely release of the data.

1. Background

Pakistan is a country of diverse agro-climatic regions. The climate is predominantly arid to semi-arid. The mighty Indus and its tributaries have facilitated the establishment of a network of dams, barrages and a profuse delivery system of water supplies. Despite a large territory, Pakistan's agriculture is predominantly centered in the Indus basin. The agriculture sector is facing certain challenges which require immediate and focused attention both at research and policy level. Sustainable agricultural growth is based on a paradigm that secures more profitable farming, high productivity of major farming systems, diversification of high value crops and demand-based production. In this regard, the present government is taking various initiatives to accelerate agricultural growth and promote investment in agricultural research (Farooq 2014).

The Government of Pakistan is in the process of upgrading and diversifying its program and capacity for an effective mechanism to ensure crop monitoring and forecasting system. Pakistan's Ministry of National Food Security & Research (MNFS&R) endeavored to improve the mobility, human resource development and service structure of Crop Reporting Departments in the country. The Ministry further opted to invest in cross cutting technologies such as Remote Sensing and GIS for gathering spatial information on agriculture/crops sector for timely interventions.

Conventionally, the crops area estimation system is based on Village Master Sampling (VMS) from the revenue department developed in the late 1970s by the Federal Bureau of Statistics, Pakistan. Ground surveys are carried out in selected sample villages and district-wise crops statistics are compiled based on a multiplier or raising factor. The crop production estimates are obtained by taking the product of crop acreage and the corresponding crop yield. The yield surveys are fairly extensive with plot yield data collected under a complex sampling design that is based on random sampling design. A plot of specified dimensions within a field is selected for harvesting to determine the crop yield. The sample units are randomly selected. Problems encountered concern subjectivity in responses, respondent differences and non-response. On a national scale, the processing of these sample data is an expensive and time-consuming procedure. In general, there is a need for an objective, standardized and possibly cheaper and faster methodology for crop growth monitoring and yield forecasts.

Traditional methods of predicting crop yields throughout the growing season include models that assimilate climate, soils and other environmental data as response functions to describe development, photosynthesis, evapotranspiration and yield for a specific crop (Wiegand and Richardson 1990). Though based on strong physiological and physical concepts, these models are poor predictors when spatial variability in soils, stresses or management practices are present (Wiegand 1984; Wiegand and Richardson 1990). However, remote sensing of crop canopies has been promoted as a potentially valuable tool for agricultural monitoring because of its synoptic coverage and ability to "see" in many spectral wavelengths (Hinzman *et al.* 1986; Quarmby *et al.* 1993). Numerous studies have recognized that plant development, stress and yield capabilities are expressed in the spectral reflectance from crop canopies and could be quantified using spectral vegetation indices (Jackson *et al.* 1986; Malingreau 1989; Weigand and Richardson 1990). Vegetation indices (VI), such as the Normalized Difference Vegetation Index (NDVI), are typically a sum, difference or ratio of two or more spectral wavelengths. They are highly correlated with photosynthetic activity in non-wilted plant foliage and are good predictors of plant canopy biomass, vigor or stress (Tucker 1979). Vegetation monitoring using the red and near infrared SPOT VGT channels has been one of the most widely used indices. The Normalized Difference Vegetation Index (NDVI) correlates closely with green biomass and the leaf area index. Despite the spatial resolution of 1 km at nadir, there are many scientific publications documenting the usefulness of SPOT VGT data as a means of monitoring vegetation conditions on a near real-time basis (Philipson and Teng 1988; Bullock 1992; Quarmby *et al.* 1993).

There was a need to develop fast and reliable procedures to make crop forecasts and estimations early in the season or at the end of the season. The Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), the Space Agency of Pakistan, started developing crop area estimation procedures and crop yield models, based on the application of satellite remote sensing, GIS technology, agronomy, agro-meteorology, statistics and other allied disciplines.

2. Material and methods

A satellite-based crops monitoring system in Pakistan has been developed to forecast and estimate crops statistics of major crops which include wheat, rice, cotton, sugarcane, maize and potato since 2005 (Bussay and Akhtar 2009, Obaid ur Rehman *et al.* 2010, 2011). Crops area estimates are based on two approaches: 1) satellite data supervised classification; and 2) area frame sampling system. Yield modeling is based on FAO's approach of yield relationship with predictor variables.

2.1 Area estimation approach

This describes the crops area estimation system developed at SUPARCO.

2.1.1 Development of SRS/GIS-based area frame sampling system

This system has been developed based on crops peak stage satellite data of February and September. This was done through defining different stratum based on agriculture fields and cropping intensity. The land use was stratified into ten different homogenous stratum based visual interpretations (Table 1).

Table 1. Different stratum and definitions

S. No.	Stratum	Description
1	11	Intense Cropland (75–100% agriculture area)
2	12	Less intense Cropland (50–75% agriculture area)
3	21	Cropland Pasture Mixed (25–50% agriculture area)
4	42	Mostly Pasture (<25% agriculture area)
5	13	Un-identified seasonal vegetation
6	14	Areas rarely under vegetation
7	31	Rural area around city (Less that 50 houses/km^2)
8	32	Inter city
9	50	Non farmland (Desert, Forest, Saline, establishments)
10	60	Water bodies (Rivers, Canals)

These strata were apportioned into Primary Sampling Units (about 5 000 to 10 000 ha each) (PSU) and Secondary (1 000-2 000 ha each) Sampling Units (SSU). These units were allotted serial numbers in a serpentine design through using tailor-made software. Pakistan was divided into nine zones, viz. Punjab 4, Sindh 2, Khyber Pakhtunkhwa 2 and Balochistan 1. Initially, 20 to 30 sampling units called segments, depending upon the cropping intensity, of a size of approximately 30 ha each, were selected from all stratum in each zone based on probability proportional to the area. The fractional segments in each stratum were taken as a whole unit. These sampling units were doubled in the subsequent years to assure synchronization of crop data with parallel techniques of image classification. The total number of segments in nine region is 379 (Table 2).

Table 2. Province and region wise number of selected ground samples (Segments)

Province	Region	No. of segments
Punjab	Potohar	21
	North East	46
	Central	75
	Southern	78
Sindh	Left bank of Indus	52
	Right Bank of Indus	42
KP	North	20
	South	20
Balochistan		25
Total		379

Based on the area frame sample designing, Raising Factors (RF) were developed to estimate crop area sown in each stratum in each zone/region. These RF values helped to work out crop area sown under various crops, by a statistical design. A critical examination of the data generated was made by a team of experts in the field of Agronomy, Remote Sensing and Statistics to standardize this technique by image classification and historic trend lines. The team suggested valuable improvements in each cropping season and these changes were incorporated in the technique.

2.1.2 Satellite image classification technique

Satellite data image classification is based on satellite data acquisition of specific time, ground truth surveys during cropping season, crops signature collection, lab processing, accuracy assessment and crop area estimation.

2.1.2.1 Acquisition of imagery

Country-wide acquisition of satellite imagery was done for rabi and kharif crops twice at the following stages:

- First at four weeks after the completion of sowing.
  (June-July for kharif crops and December-January for rabi crops)
- Second at eight weeks after completion of sowing.
  (August for kharif crops and February-March for rabi crops)

2.1.2.2 Ground Truth Surveys (GTS)

Extensive programs were devised to undertake ground truth surveys to collect crops-related information during the season. Field teams visited the sampling segments through real-time navigation through GPS devices.

2.1.2.3 Satellite image classification

The data gathered from the field were digitized. The image classification was done by developing spectral signatures of crops by using multi-date imagery. Image classification was carried out by supervised classification using the Gaussian maximum likelihood method on different work units and an area estimation was carried out using image processing software.

2.2 Crop yield modeling for forecasting and estimation

The important procedural steps in crop yield modeling/forecasting and estimation are as follows (Bussay and Akhta 2008, 2009).

2.2.1 Development of database

A spatial database consisting of data for the last 15 years (1998 and onward) for various variables responsible for change in crop yield was developed. These include district-wise crop statistics, agro meteorological data for 36 stations covering min/max temperature, rainfall and relative humidity. The sunshine duration data was available for 8 stations. The sunshine duration data was deemed to be very useful in the crop yield forecast as the radiation is an important limiting factor of crop production after soil moisture availability. Daily maximum and minimum temperatures were applied in the Hargreaves formula to fill the gaps in the calculated global radiation time-series. The minimum and maximum temperature was applied through the Hargreaves formula to complete the days with missing data. Hargreaves formula estimates the global radiation on the basis of daily temperature range using the maximum (Tmax) and minimum (Tmin) temperatures:

$$H = H_0 \cdot k_{RS} \cdot \sqrt{T_{\max} - T_{\min}}$$

Where Hargreaves coefficient k_{RS} is between 0.16 (inland stations far from the sea) and 0.19 for stations at the sea-side. The (T_{max} – T_{min}) difference is the daily temperature amplitude.

2.2.2 Harmonization and integration of the data

The data were harmonized for various spatial (polygons) and time scales (converted from daily to decadal). Spatial interpolation of the point data was done at a grid size of 0.05 degrees for the whole country (Javid *et al.* 2010). The current year's data were used to integrate with the historic data and forecast crop yields based on statistical modeling.

2.2.3 Crop phenology and modeling from SPOT VGT data

The important phenological stages of crop growth include: a) time of emergence; b) time of peak growth; and c) time of ripening/senescence (M.H. Khan *et al.* 2007). The time of emergence of a crop or more precisely the time of beginning of measurable photosynthesis on a satellite vegetation image seasonal profile is termed as the starting decadal. The increment is within the range of 0.01-0.05 per decadal depending on total cropped area and growth stage under the pixel of the satellite image. The time of peak growth or end of the growing period and beginning of flowering is the period of maximum greenness or maximum photosynthesis and is called the peak decadal. The peak decadal has the highest NDVI value of the cycle. The date of senescence or harvest (cessation of measurable photosynthesis) is called the ending decadal. It occurs at a minimum of 3 decadals after peak decadal. The course of previous NDVI values is decreasing and the following NDVI values have increasing trend or the course is flattened.

2.2.4 Development of calibration matrices and model development

The matrices were developed for all variables responsible for change in crop yield (Akhtar, 2011),

2.2.4.1 Principal component analysis

This is one of the main components of the model calibration which reduces the dimensional aspects of all independent variables defining the crop yield.

2.2.4.2 Correlation matrix

This analysis is carried out to find the possible co-linear relationship within PCA derived variables to reduce the biasness in final model. The co-linear variables are identified and only those with moderate to high independency nature are used in model calibration.

2.2.4.3 Outlier detection

This step is necessary to remove the suspicious observations with the help of statistical tests, mainly Whisker Box plot or cook distance techniques. This improves the model accuracy and eliminates the bias extremes cases.

2.2.4.4 Multiple regression analysis

Multiple regression analysis is carried out between the selected independent variables which are significantly responsible for change in yield. At the end of model calibration, the model-based error in yield/production forecast/estimation is carried out to define the confidence interval of the forecast/estimates (Variance, Average Absolute error, Average error, etc.). Validation is based on model output at different spatial scales like the production.

2.3 Forecasting and estimation of agricultural statistics

Crop area estimates are made available after the ground survey campaign and image processing of the seasonal acquired data, crop yield modeling and quality assessment.

3. Results and discussion

The satellite-based crops monitoring system in Pakistan flourished after 2005 due to its timeliness and reliability of crop statistics. Crops area estimation through area frame sampling system mainly relies on the quality of ground data collected during the season in sample segments (Figure 1). This field information on crops sown in each segment was digitized in ArcGIS software. Digitization of the samples was carried out at 1:3 000 scales to avoid any field size impact on crops area estimation (Figure 2). The segments based crops information summarized by the stratum and raising factor were used to estimate the sample-based crops estimates.

Besides Area frame sampling, satellite image classification was used to estimate the crops acreage using SPOT-5 satellite data of the different times during the growing season including early growth and peak growth of crops (Figure 3). Early season image shows that the majority of crops are still under the sowing stage whereas peak season satellite data reflects fields with actively growing crops.

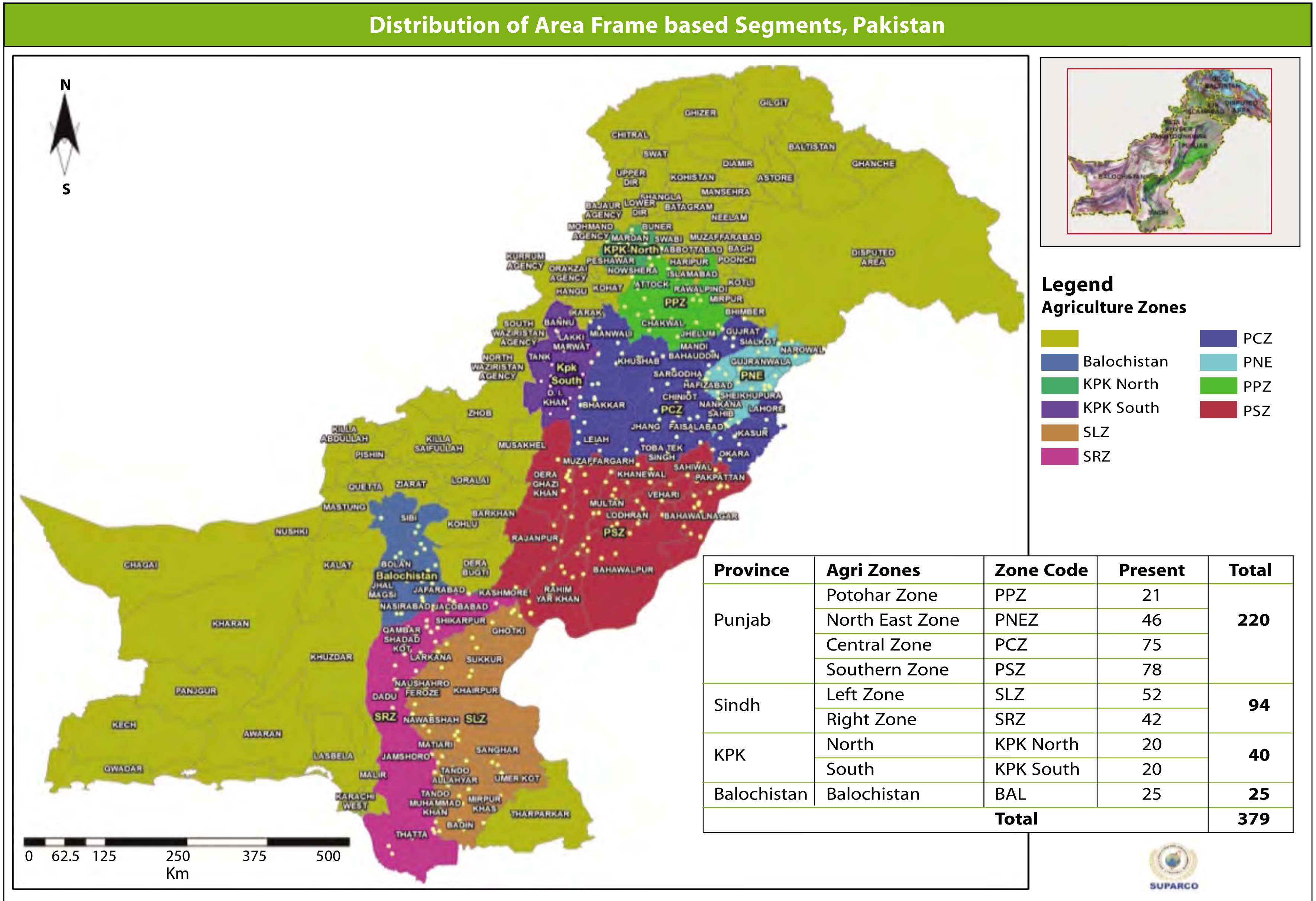
Supervised classification with the Gaussian Maximum Likelihood method was adopted. Information on agriculture and non-agriculture were collected during the ground truth survey. Random independent crops signatures were also collected during survey to compensate the spatial context in the Segments information (Figure 4). These marked fields points were divided into training (70 percent) and testing (30 percent) data through the random selection tool in ArcGIS software. Training data was used to train the supervised classifier and classified data was produced as an output (Figure 5). Overall, classification ranged between 85–95 percent depending on the satellite data quality, number of crops grown, crop type and topography of the area. Quality of classified data was assessed through confusion matrix analysis by using independent testing data. Overall, quality tests proved to be a useful method to revisit less quality classified data. Accuracy assessment of data ranged from 85-95 percent. The classified data were sub-setted at the administrative level to compile the district-wise crops estimates. These estimates were compared with those released by Government of Pakistan, such as for wheat (Table 3).

Crop yield forecasting and estimation cover are an important dimension of crops statistics, being of mostly qualitative nature. SPOT vegetation data is the main yield predicting variable in all calibrated models. Crop phenology was mapped along with the related NDVI values to find out the direct relationship with crop yield. The spatial database was developed into a model calibrating matrix. NDVI profile helped to differentiate the crop performance during different years (Figures 6 and 7).

PCA was applied to reduce the dimensionality in the predictor variables (Figure 8). Significant variables explaining the variance of 99 percent were selected. These selected variables were tested with the multi-colinear test to identify the false relationship among predictor variables to reduce the bias in the multiple regression crop yield model.

All major crops models including wheat, cotton, rice, sugarcane and maize were calibrated for yield forecasting during the initial to peak growth season and estimated near harvest time. Yield historical data was regressed with multiple predictor variables and only the most significant variables were selected (Figure 9).

Model parameters with their coefficients were used to estimate yield for each crop for the current season (Table 3).



Province	Agri Zones	Zone Code	Present	Total
Punjab	Potohar Zone	PPZ	21	**220**
	North East Zone	PNEZ	46	
	Central Zone	PCZ	75	
	Southern Zone	PSZ	78	
Sindh	Left Zone	SLZ	52	**94**
	Right Zone	SRZ	42	
KPK	North	KPK North	20	**40**
	South	KPK South	20	
Balochistan	Balochistan	BAL	25	**25**
		Total		**379**

Figure 1. Satellite based Area Frame Sampling System showing distributed Ground Survey Samples (Segments)

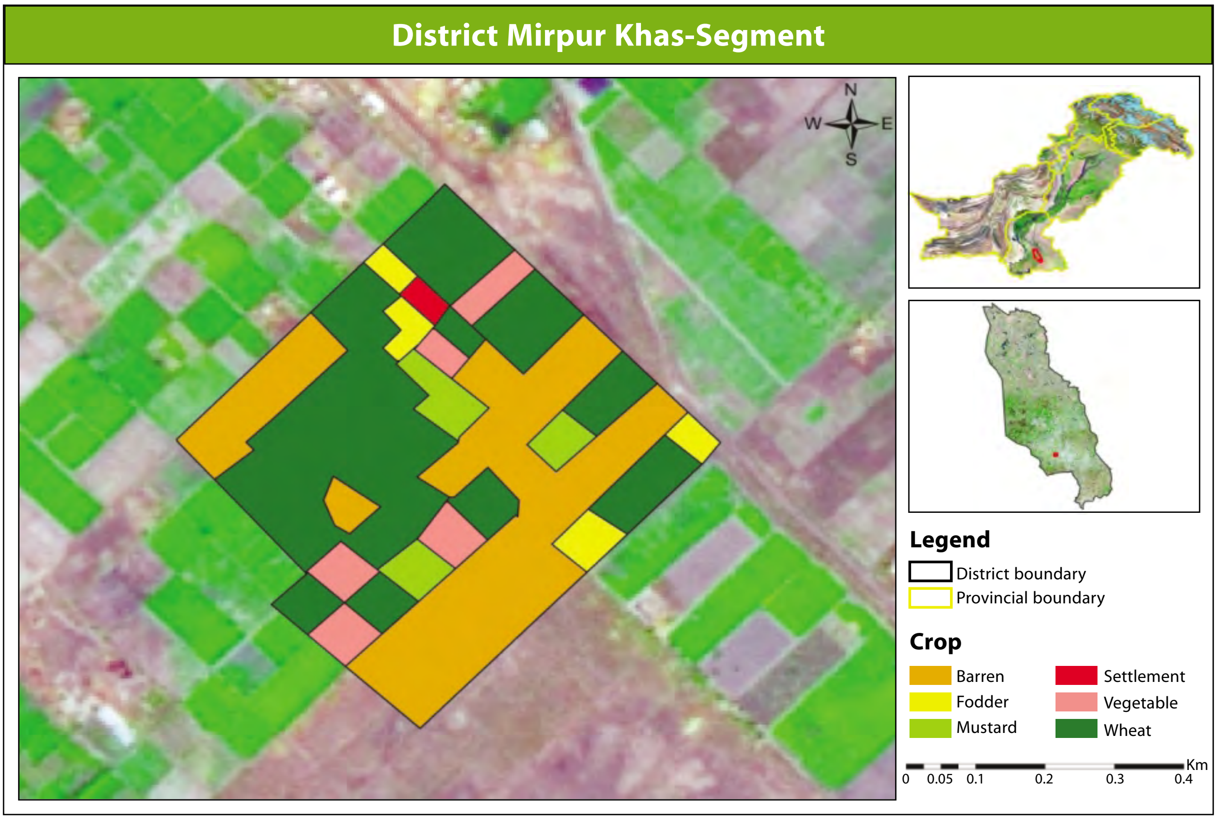


Figure 2. Ground Surveyed Segments and Digitized Information

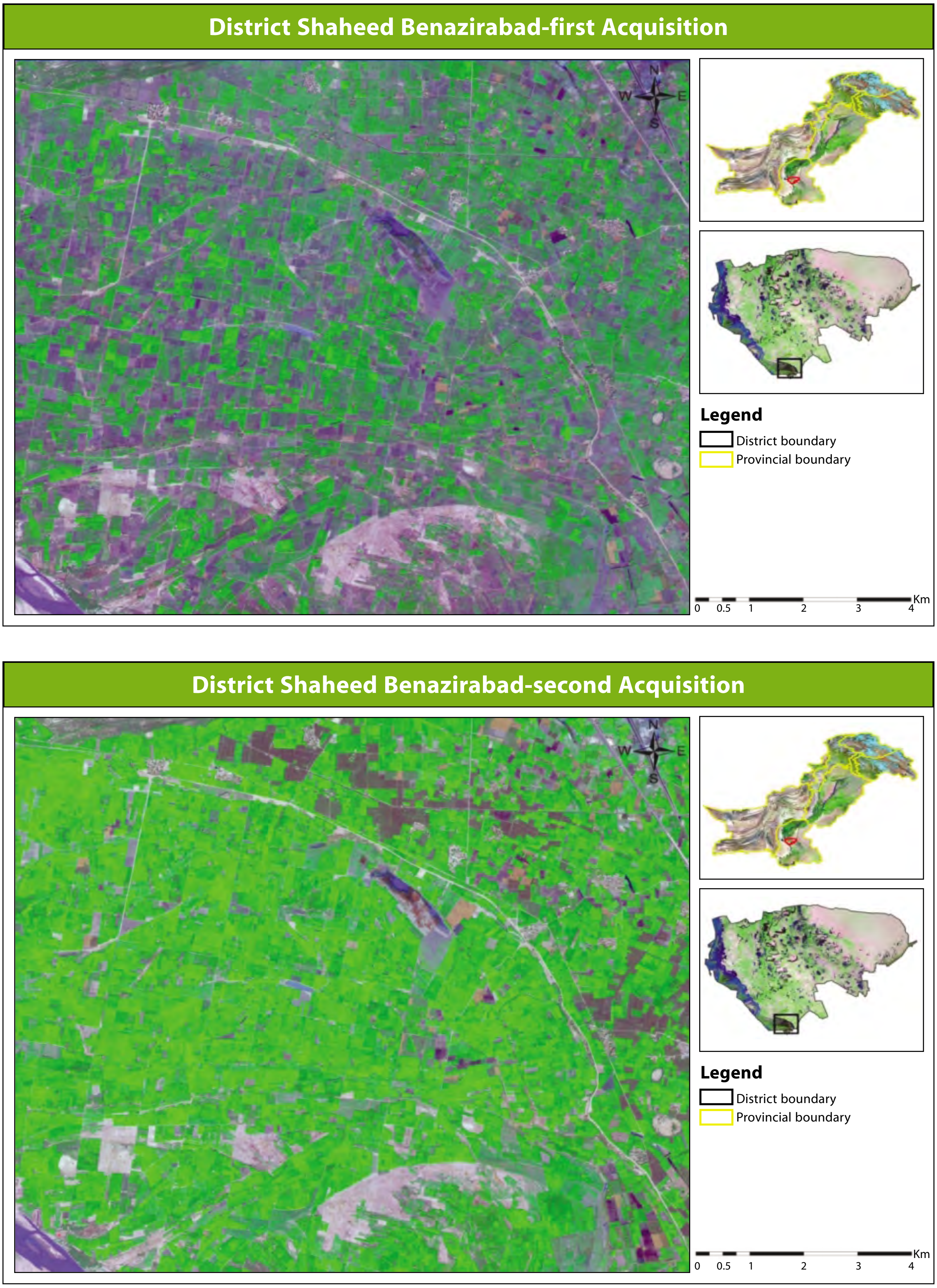
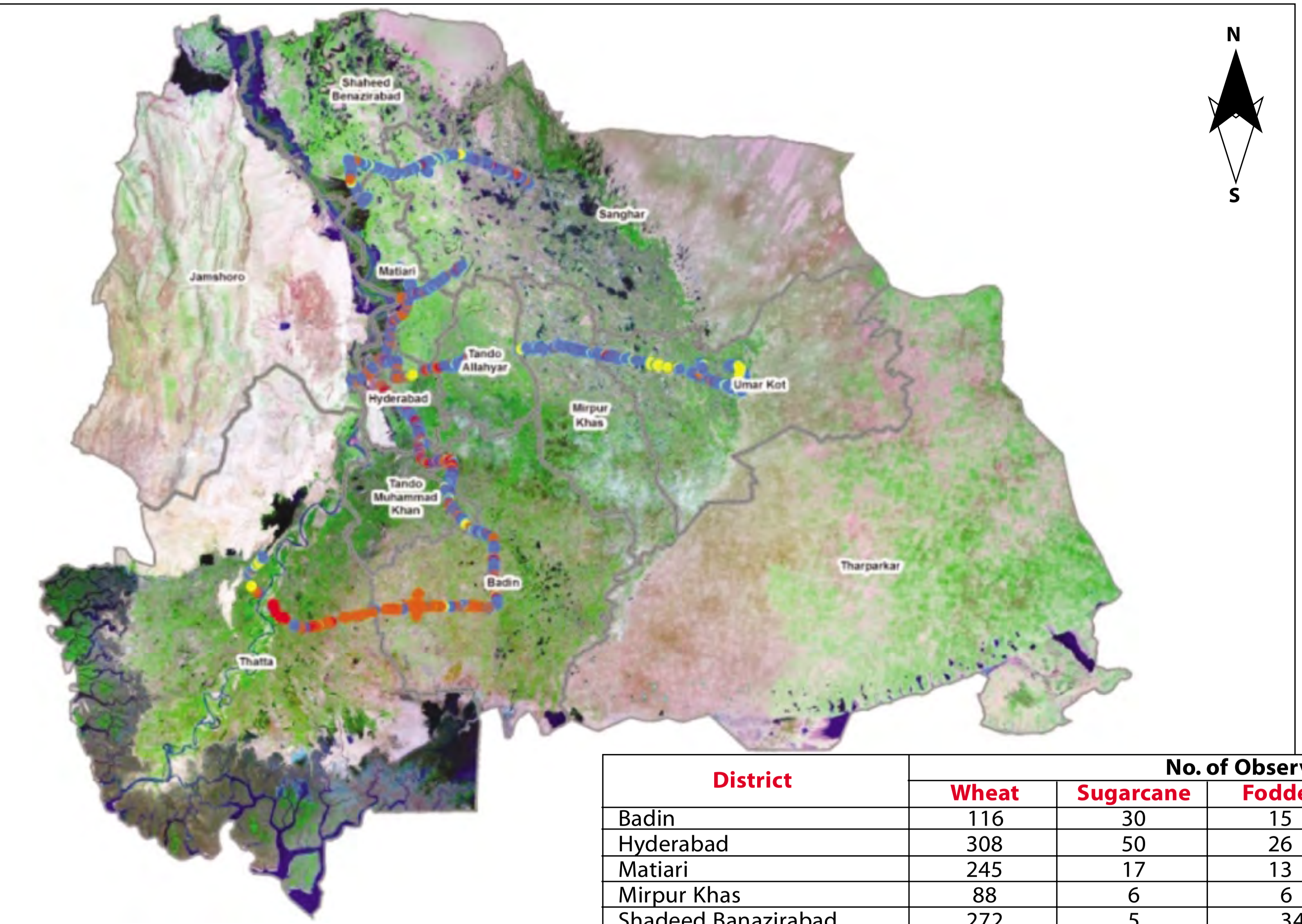
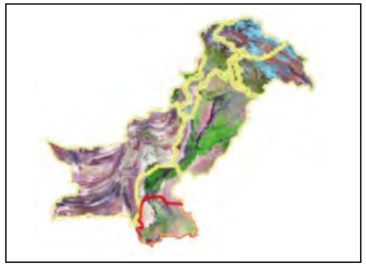


Figure 3. SPOT5 satellite data (1st and 2nd acquisitions)





District	No. of Observed Field				
	Wheat	Sugarcane	Fodder	Other	Grand Total
Badin	116	30	15	209	370
Hyderabad	308	50	26	132	516
Matiari	245	17	13	86	361
Mirpur Khas	88	6	6	3	103
Shadeed Banazirabad	272	5	34	5	326
Sanghar	499	53	62	43	657
Tando Allahyar	61	13	1	16	91
Thatta	53	31	25	47	156
Umar Kot	144	9	61	15	229
Jamshoro	15	0	0	5	20
Tando Muharmmad Khan	131	58	14	37	240
Grand Total	1 932	272	257	608	3 069

Figure 4. Crops Fields on two different time SPOT5 satellite data

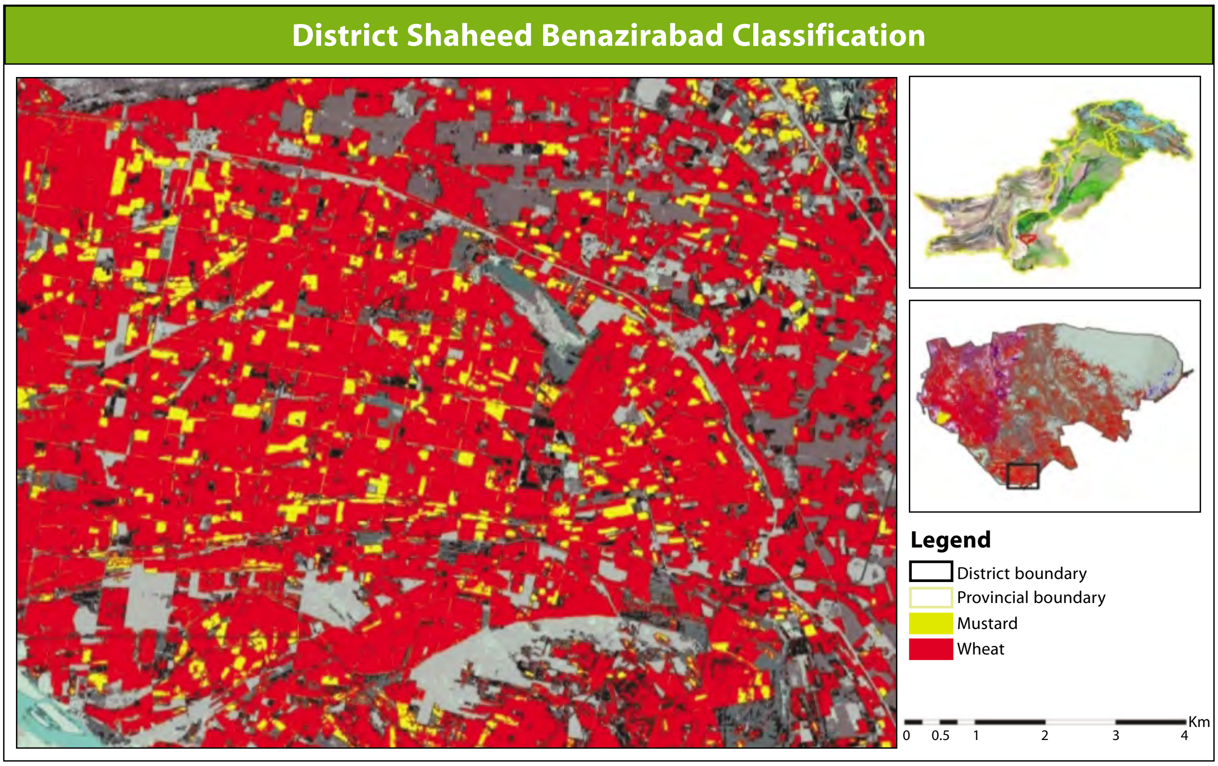


Figure 5. Classified SPOT5 satellite data

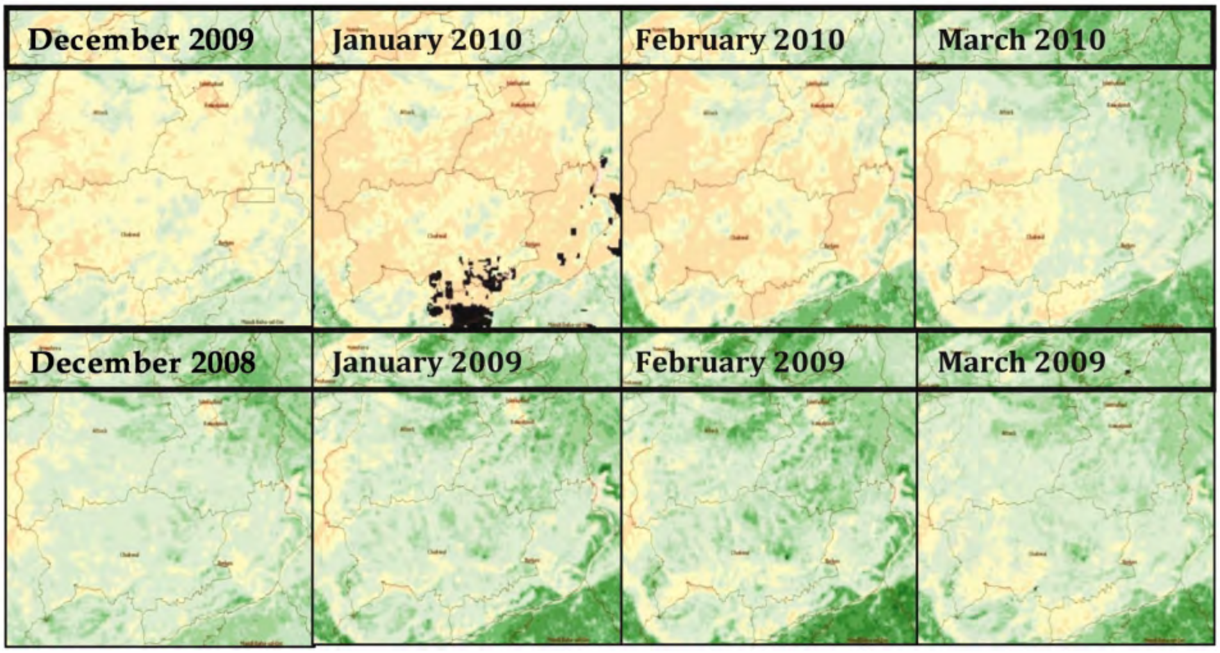


Figure 6. Monthly SPOT NDVI behavior in rainfed area of Punjab

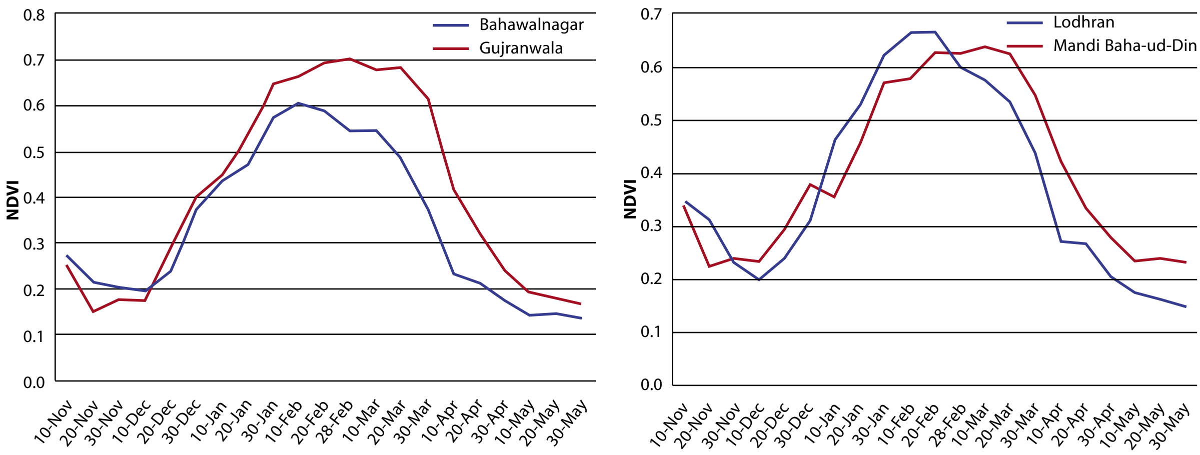


Figure 7. NDVI growth profile at district level

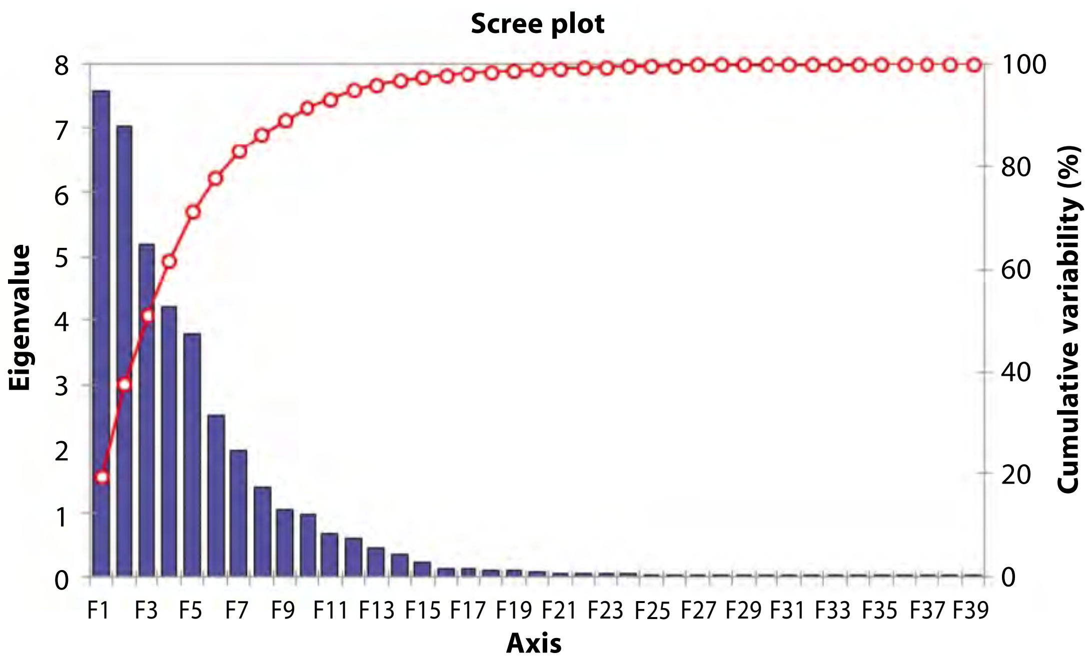


Figure 8. PCA Analysis and cumulative variation

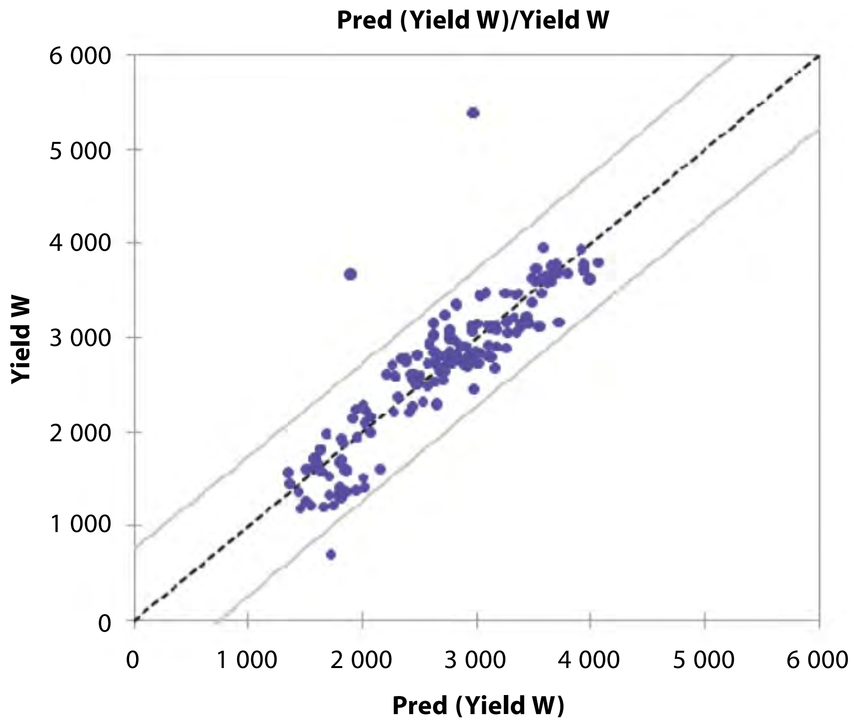


Figure 9. Model performance showing model predicted yield against observed wheat yield (kg/ha)

Table 3. Calibrated wheat crop yield model parameters and coefficients for yield estimation

Model parameters						
Source	Value	Standard error	t	Pr > (t)	Lower bound (95%)	Upper bound (95%)
Intercept	1 549.003	769.794	2.012	0.052	-12.211	3 110.217
ppt_nov-mar	1.554	0.219	7.103	<0.0001	1.110	1.997
Mxt10	62.588	11.400	5.490	<0.0001	39.467	85.709
ppt_jan	5.669	0.853	6.646	<0.0001	3.939	7.399
Amp15	-112.037	20.551	-5.452	<0.0001	-153.716	-70.357
Mxt5	-112.256	23.547	-4.767	<0.0001	-160.011	-64.500
Mnt4	129.066	24.143	5.346	<0.0001	80.103	178.030
Yavg	0.825	0.149	5.525	<0.0001	0.522	1.127

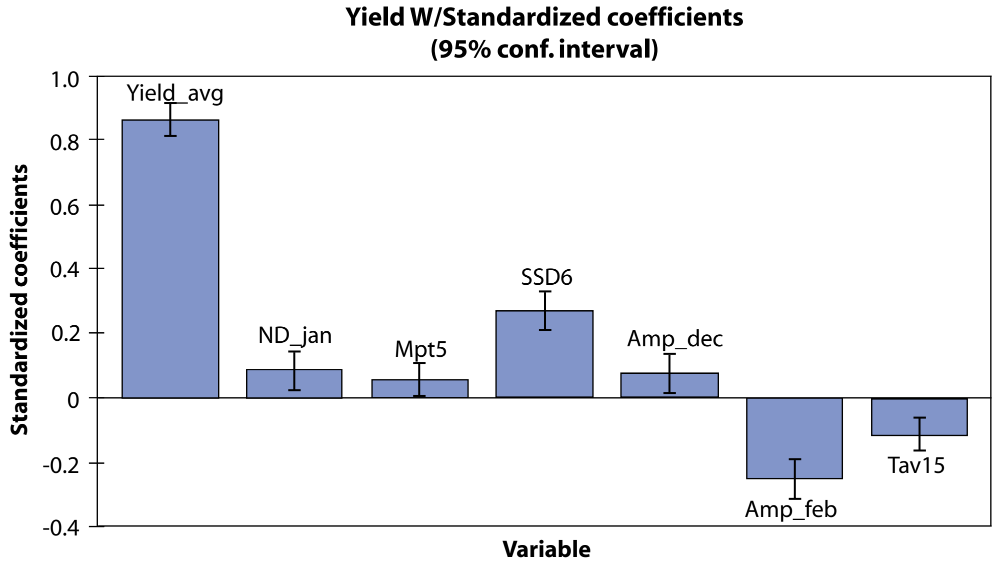


Figure 10. Model parameters co-efficient value with standard error

Satellite data-based crops area and yield estimation were compiled and compared later with official government statistics (Table 4). This comparison was to outline the significance of the data being produced through the satellite technology system. SUPARCO has developed a crop monitoring system based on satellite data, whereas the agriculture department estimation system is based on revenue department village census data. The main advantage of the SUPARCO satellite-based crops system is the timely release of data. Wheat and other rabi crops statistics are released by the end of March to mid-April every year, whereas official statistics are released 4–6 months after the crop harvest from October to November.

Table 4. Comparison of wheat estimate of SUPARCO data with official statistics

Season	Province	SUPARCO Wheat Estimates			Official Statistics of Wheat			Difference (%)		
		Area (000 ha)	Yield (kg/ha)	Production (000 tons)	Area (000 ha)	Yield (kg/ha)	Production (000 tons)	Area	Yield	Production
2010-11	Punjab	6 695.0	2 764.0	18 505.0	6 691.0	2 845.8	19 041.0	0.1	-2.9	-2.8
	Sindh	1 509.0	2 585.0	3 900.8	1 144.4	3 746.8	4 287.9	31.9	-31.0	-9.0
	K.P	645.2	2 015.0	1 300.1	724.5	1 595.4	1 155.8	-10.9	26.3	12.5
	Balochistan	305.0	1 967.9	600.2	340.8	2 139.6	729.1	-10.5	-8.0	-17.7
	Pakistan	**9 154.2**	**2 655.2**	**24 306.1**	**8 900.6**	**2 832.8**	**25 213.8**	**2.8**	**-6.3**	**-3.6**
2011-12	Punjab	6 621.0	2 270.0	18 340.2	6 482.9	2 736.2	17 738.9	2.1	-17.0	3.4
	Sindh	1 482.2	2 519.0	3 733.7	1 049.2	3 585.2	3 761.5	41.3	-29.7	-0.7
	K.P	757.9	1 599.0	1 211.9	729.3	1 549.9	1 130.3	3.9	3.2	7.2
	Balochistan	349.0	2 133.0	744.4	388.4	2 169.7	842.7	-10.1	-1.7	-11.7
	Pakistan	**9 210.1**	**2 609.0**	**24 030.2**	**8 649.8**	**2 713.7**	**23 473.3**	**6.5**	**-3.9**	**2.4**

4. Conclusion

Remote sensing-based agriculture monitoring is an important component of the food security information system which provides reliable and timely crop area estimates and crop production forecasts at national, regional and global scales. The system contributes to support policy making to ensure food security. To develop fast and reliable procedures to make crop forecasts and estimations early in the season or end of season, the Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), the Space Agency of Pakistan, started to develop crop area estimation procedures and crop yield models based on the application of satellite remote sensing, GIS technology, agronomy, agro-meteorology, statistics and other allied disciplines. A system has been developed based on 2.5 to 10 meter high resolution and SPOT Vegetation data of one square kilometer. The image acquisition was carried twice during each cropping season at a time span of 4 weeks and 8 weeks after sowing of crops.

Satellite data-based crops area and yield estimation were compiled and compared later with official government statistics. The SUPARCO satellite-based crops system provides fast and reliable crop forecasts and estimates.

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Use of remote sensing in crop forecasting and assessment of impact of natural disasters: operational approaches in India

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Key words: FASAL, NADAMS, Crop Forecasting, Drought Assessment, Remote Sensing

ABSTRACT

Use of remote sensing data for pre-harvest crop production forecast has been operationalized in India under a national-level programme called Forecasting Agricultural output using Space, Agro-meteorology and Land-based observations (FASAL). The FASAL programme, funded by the Ministry of Agriculture, envisages multiple production forecasts of major crops of the country at National/State/District levels. Similarly, under the National Agricultural Drought Assessment and Monitoring System (NADAMS) project, remote sensing data from multiple sources are integrated with ground and meteorological information for district/sub-district level drought assessment for 13 states of India. The methodology for both of these programmes was developed by the Indian Space Research Organization and later on transferred to a centre (Mahalanobis National Crop Forecast Centre) specifically created under the Ministry of Agriculture to operationalize space technology applications in agriculture.

1. Introduction

In India, agriculture is one of the major application areas of remote sensing technology. Various-national level agricultural applications have been developed which showcases the use of remote sensing data provided by the sensors/satellites launched by the country's space agency, Indian Space Research Organisation (ISRO). Some of these applications include crop acreage and production estimation, cropping system analysis, agricultural water management, drought assessment and monitoring, horticultural development, precision farming, soil resources mapping, potential fishing zone forecast, watershed development, climate impact on agriculture and so on (Navalgund and Ray 2000; Panigrahy and Ray 2006; Navalgund *et al.* 2007). A few of these applications, after reaching operational level, have been transferred to the user departments. This has resulted in the institutionalization of the remote sensing applications in the country (Parihar and Manjunath 2013). One recent example of operationalization/institutionalization of remote sensing application is the creation of a centre called Mahalanobis National Crop Forecast Centre (MNCFC) under the Department of Agriculture & Cooperation, Ministry of Agriculture. The centre operationalizes two major programmes developed by ISRO on crop forecasting and drought assessment apart from various other activities related to agricultural assessment. This article describes these operational approaches.

2. Crop forecasting

Crop forecasting is essential for various agricultural planning purposes, including pricing, export/import, contingency measures, etc. Crop forecasting using remote sensing data, in India, started in the late 1980s in the Space Applications Centre of ISRO under the Department of Agriculture and Cooperation's (DAC) sponsored project CAPE (Crop Acreage and Production Estimation). This later on developed into a national level programme, called FASAL (Forecasting Agriculture output using Space, Agro-meteorology and Land-based observations), which has been in operation since August, 2006. The FASAL project aims at providing multiple pre-harvest production forecasts of crops at National/State/District levels (Parihar and Oza 2006). Remote sensing data, both optical and microwave form the core of crop area enumeration, crop condition assessment and production forecasting. Crop yield is estimated using agro-meteorological/spectral yield models and also crop growth simulation models. The FASAL approach also involves using econometric models to forecast the area and production before the crop sowing operations. FASAL is a multi-institutional programme, which integrates the activity from many organizations. The list of such organizations is given in Table 1. MNCFC has started providing crop forecasts under the FASAL programme from the kharif (rainy) season of 2012.

Table 1. Organizations involved in FASAL programme and their responsibilities

S.N.	Name of the Organisation	Responsibility
1	Directorate of Economics & Statistics, Ministry of Agriculture	Overall Coordination
2	Mahalanobis National Crop Forecast Centre, Ministry of Agriculture	Operational Crop Assessment
3	Space Applications Centre, Indian Space Research Organisation	Techniques Development
4	India Meteorological Department	Crop Yield Forecasting
5	Institute of Economic Growth	Econometric Modelling for pre-season forecast
6	State Agricultural Departments	Ground truth collection
7	State Remote Sensing Application Centres	Support for Techniques Development Activities

Currently, under the FASAL project, national and state level multiple forecasts are being issued for 5 crops: rice (kharif and rabi), jute, rapeseed and mustard, winter potato and wheat. From 2013-2014 onwards, state and district level forecasts are generated for cotton, sugarcane and rabi (winter season) sorghum. While multi-date SAR (Synthetic Aperture Radar) data of Indian SAR satellite RISAT-1 is used for rice (kharif and rabi) (Figure 2) and jute, multi-date Resourcesat-2 AWiFS (Advanced Wide Field Sensor) data, with 56 m spatial resolution, are used for other crops. LISS III data, with 23.5 m resolution, is being used for district-level assessments. A stratified random sampling approach is followed for crop area estimation. All those states, which together contribute more than 90 percent of the particular crop's area in the country, are considered for area and production assessment. A hierarchical/logical classification approach is followed for classifying multi-date SAR data. A hybrid (combination of supervised and unsupervised) classification method is followed for multi-date optical data, while maximum likelihood (MXL) is followed for single date optical data. Indigenously-developed software, called FASALSoft (Manthira Moorthi *et al.* 2014) is used for carrying out the digital analysis of remote sensing data. The yield forecasts are generated under the FASAL programme by the India Meteorological Department, correlation weighted empirical agro-meteorological models. For rice and wheat crops the final yield forecasts are being given using physical models with inputs from remote sensing data (Chakraborty *et al.* 2005; Tripathy *et al.* 2013). The details of the crop forecasts given in 2013-2014 are presented in Table 2. Typically, in an agricultural year, 16 crop forecasts are generated. A comparison with the official estimates of the Ministry of Agriculture showed that the remote sensing-based area estimates at the national level are within -0.5 to -8.8 percent, while differences in production estimates ranged between -11.2 to 5.6 percent.

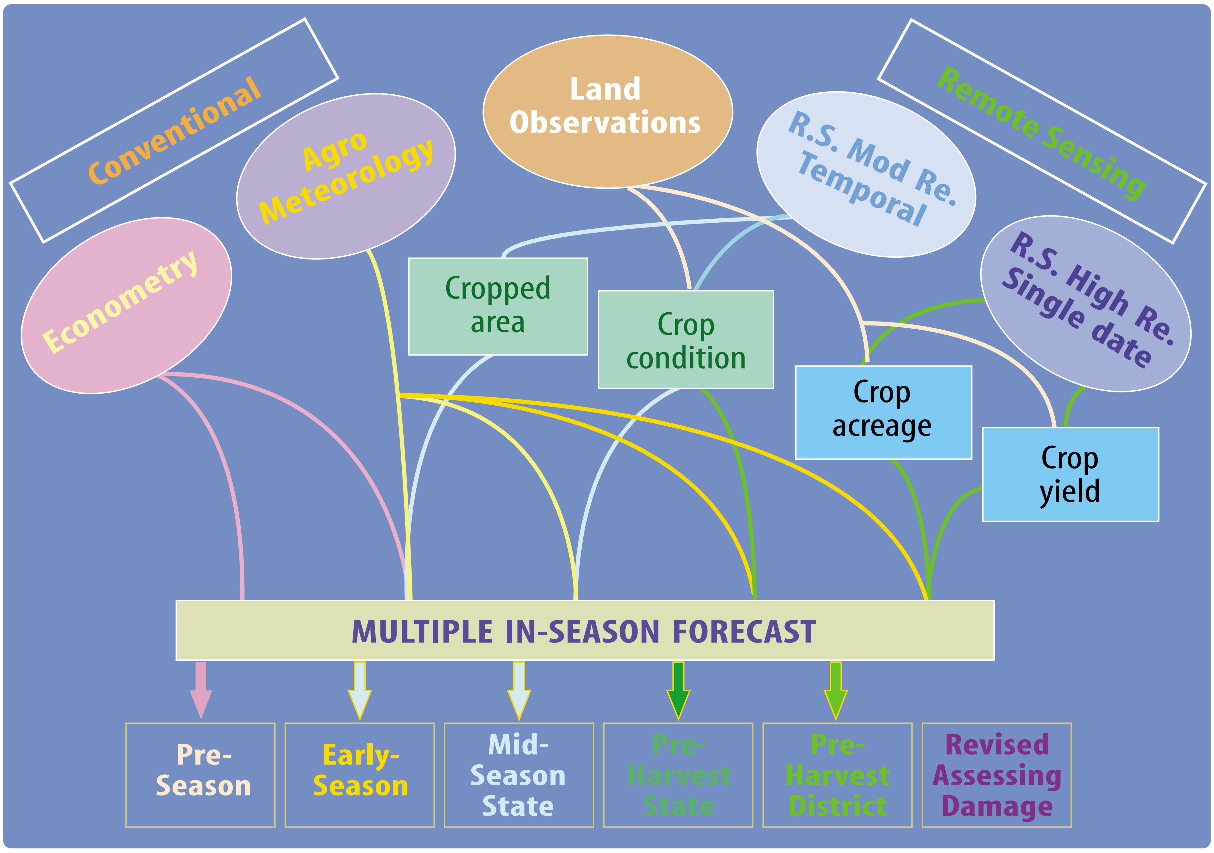


Figure 1. Approaches followed for multiple forecasts under FASAL programme (Source: SAC, ISRO)

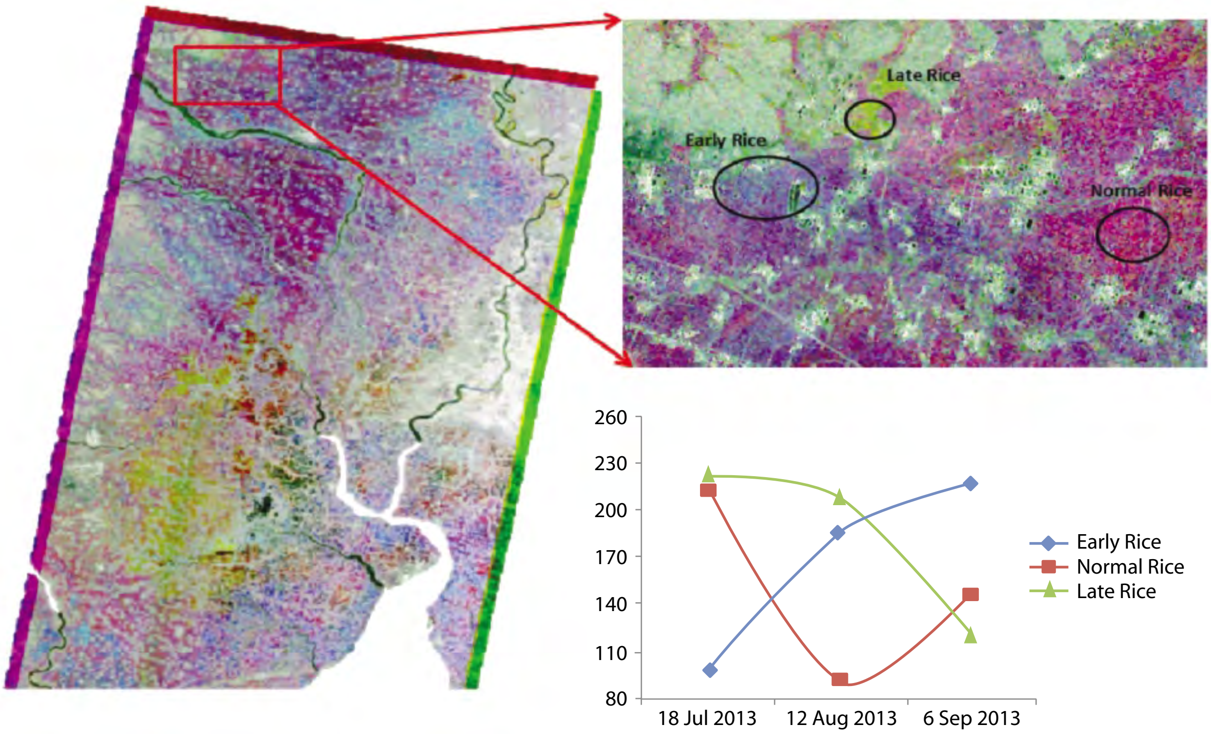


Figure 2. A typical 3-date RISAT-1 colour composite showing rice crop of different transplanting time

Table 2. Summary of crop forecasts generated under FASAL project during 2013-2014

Crop	No. of States	Forecasts	Dates of Forecasts	Satellite Data Used
Jute	3	F1	Jul. 24, 2013	RISAT-1 SAR
Rice (Kharif)	13	F1 F2 F3	Aug. 31, 2013 Sep. 30, 2013 Jan. 22, 2014	RISAT-1 SAR RISAT-1 SAR RISAT-1 SAR
Sugarcane	3	F1	Dec. 18, 2013	R2 LISS III
Cotton	7	F1	Dec. 18, 2013	R2 LISS III
Rapeseed & Mustard	5 5 6	F1 F2 F3	Dec. 31, 2013 Jan. 31, 2014 Feb. 28, 2014	R2AWiFS R2 AWiFS R2 LISS III
Winter Potato	4 5	F1 F2	Jan. 31, 2014 Mar. 04, 2014	R2 AWiFS R2 LISS III
Wheat	9	F1 F2 F3	Feb. 15, 2014 Mar. 11, 2014 Apr. 04, 2014	R2AWiFS R2 AWiFS R2 LISS III
Sorghum (Rabi)	2	F1	Feb. 15, 2014	R2 LISS III
Rabi Rice	4	F1	Apr. 04, 2014	RISAT-1 SAR

R2 – Resourcesat-2 satellite

2.1 Ground Truth collection using smart phone

Ground Truth (GT) is an essential component for remote sensing data analysis. Ground Truth includes collection of GPS readings, photographs, preparing a sketch of the field layout and filling up the GT form. Earlier, GT was being collected using a GPS, a camera and filling up a form. A recent initiative was made for smart phone-based GT collection. An Android-based application was developed by the National Remote Sensing Centre of ISRO (Figure 3a). State Agriculture Department officials collected GT using smart phones provided by MNCFC. The GT information directly comes to the Bhuvan server (ISRO's Geoportal), which can be downloaded and used real-time (Figure 3b). During the kharif and rabi season of 2013-2014 more than 5 800 GT points were collected from 16 states using the smart phones.

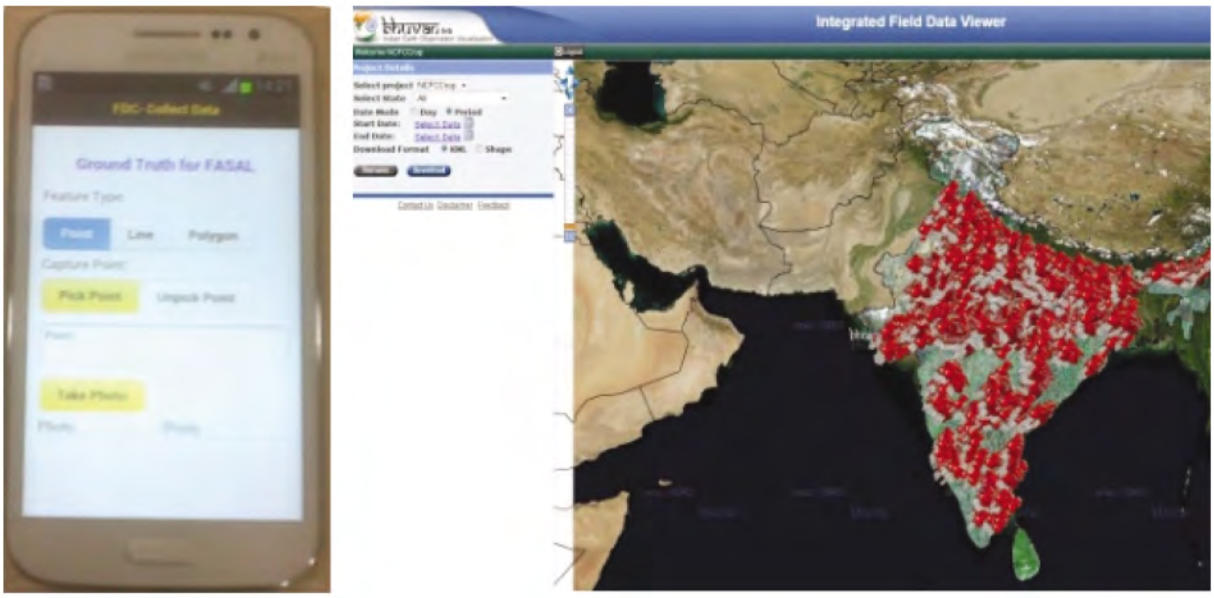


Figure 3. Real time ground truth collection using smart phone, a) Android app developed by NRSC, b) Ground Truth sites available on Bhuvan server

2.2 Remote sensing-based crop cutting experiments

Crop cutting experiments (CCE) are carried out for each crop to estimate crop yield at district and state levels. The conventional method CCE planning does not consider the current crop condition, which may result in errors in sampling. To overcome this, remote sensing-driven crop cutting experiments (CCE) planning was carried out in Bihar State for the rice crop during the kharif season of 2013. The work was carried out jointly with the Bihar Agriculture Department. A rice crop map was generated using RISAT-1 MRS data. Resourcesat-2 AWiFS time composite NDVI during September 2nd Fortnight to October 1st Fortnight was extracted for the rice area. Three classes (A, B, C) were defined based on frequency distribution of NDVI values. Thirty-seven points were randomly selected in 22 districts of Bihar (Figure 4a). A crop cutting experiment was carried out under the supervision of MNCFC. Yield models were developed between NDVI and yield and a yield map was generated (Figure 4b). The study showed a highly efficient stratified sampling plan generated for CCE based on NDVI values.

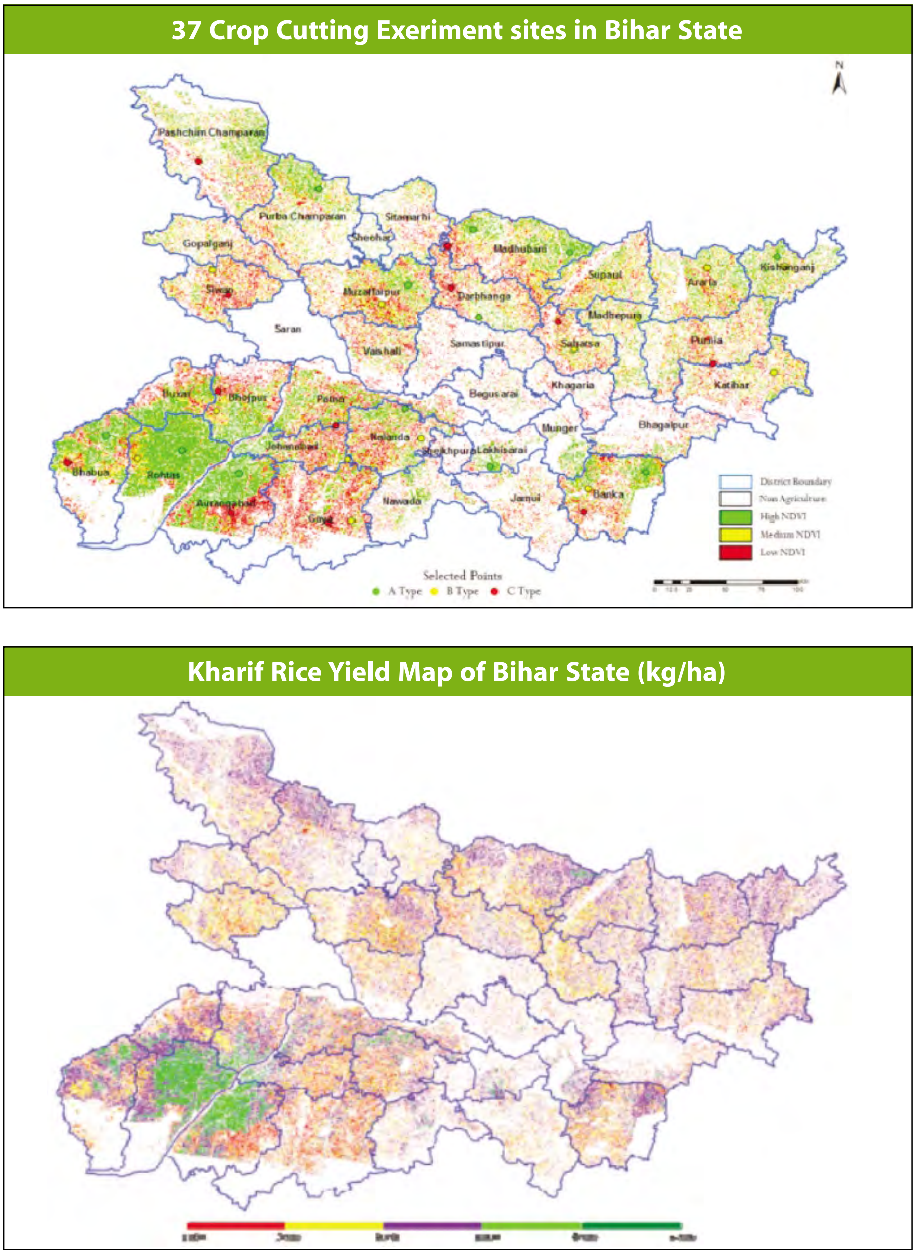


Figure 4. Use of remote sensing data for a) selecting sites for Crop Cutting Experiments for rice crop in Bihar and b) generating a yield map

2.3 Crop emergence progression

The NDVI (Normalized Difference Vegetation Index) product derived from the Indian geostationary satellite INSAT-3A-based CCD camera is extremely useful for vegetation monitoring, because of its high temporal frequency (half an hour) (Nigam *et al.* 2011). The spatial resolution of the data is 1 km. The 10-day NDVI product was used to monitor the rabi season crop emergence based on a methodology developed by the Space Applications Centre, ISRO (Vyas *et al.* 2011). Since satellite data sees the crop only after spectral emergence (i.e. the time when crops are big enough to start registering a spectral signature) this was called emergence area progression. The analysis was carried out for 6 states (Punjab, Haryana, Rajasthan, UP, MP and Bihar) at 10-day intervals during December 2013 to February 2014 (Figure 5).

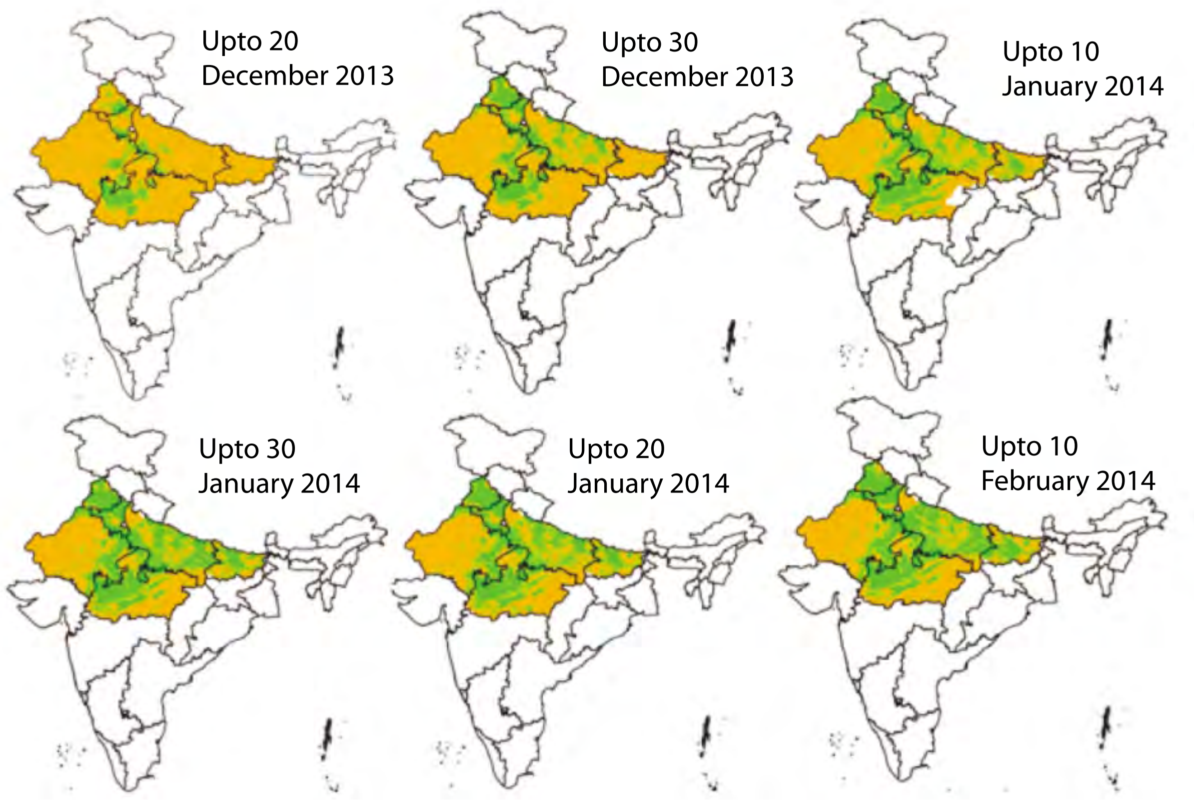


Figure 5. Map of Rabi season crop emergence area progression in 6 States of India

3. Drought and flood impact assessment on agriculture

Agriculture in India is strongly affected by two major hydro-meteorological disasters, namely droughts and floods. Droughts are a perennial feature. Sixteen percent of India's total area is drought-prone and approximately 50 million people are annually affected by droughts (DAC 2009). Over 68-70 percent of the total sown area in India is vulnerable to drought. Similarly, around 40 million hectares of land in India is prone to floods as per a National Flood Commission report.

Assessment of agricultural conditions during droughts or floods is essential for taking various relief and rehabilitation measures. Since both these disasters impact large areas, satellite-based monitoring is extremely useful.

3.1 Agricultural drought assessment

In India, operational agricultural drought assessments using remote sensing data is carried out under a major programme called the National Agricultural Drought Assessment and Monitoring System (NADAMS). The NADAMS project, developed by the National Remote Sensing Centre, provides near real-time information on prevalence, severity level and persistence of agricultural drought at state/district/sub-district levels (Murthy and Sesha Sai 2011). Currently, it covers 13 states of India (Andhra Pradesh, Bihar, Chhattisgart, Gujarat, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, Tamil Nadu, and Uttar Pradesh), which are predominantly agriculture-based and prone to drought situations. In four states (Andhra Pradesh, Karnataka, Haryana and Maharashtra), the assessment is carried out at sub-district level. The remote sensing data of NOAA AVHRR (for district level), MODIS and Resourcesat-2 Advanced Wide Field Sensor, AWiFS (for sub-district level) along with rainfall data are used for drought assessment (Choudhary *et al.* 2011). Various spectral indices, such as Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Shortwave Angle Slope Index (SASI) are computed and integrated with the Soil Moisture Index and District Level Rainfall to assess the drought condition (Figure 6). Agricultural conditions are monitored at state/district levels using daily NOAA AVHRR/MODIS data. Fortnightly/monthly reports of drought conditions are provided to all the concerned central and state government agencies under NADAMS. MNCFC has started providing periodic Drought Assessment Reports from the kharif season of 2012 (Ray *et al.* 2014).

The district level drought assessment map for September 2013 is presented in Figure 7, which shows that in the 13 states, 11 districts were in moderate drought condition and 43 districts were in mild drought condition. Every month, similar maps are generated and circulated along with all satellite-derived products. Recently a drought geo-portal has been created (www.ncfc.gov.in), where users can access the images, maps, assessments and NDVI profiles.

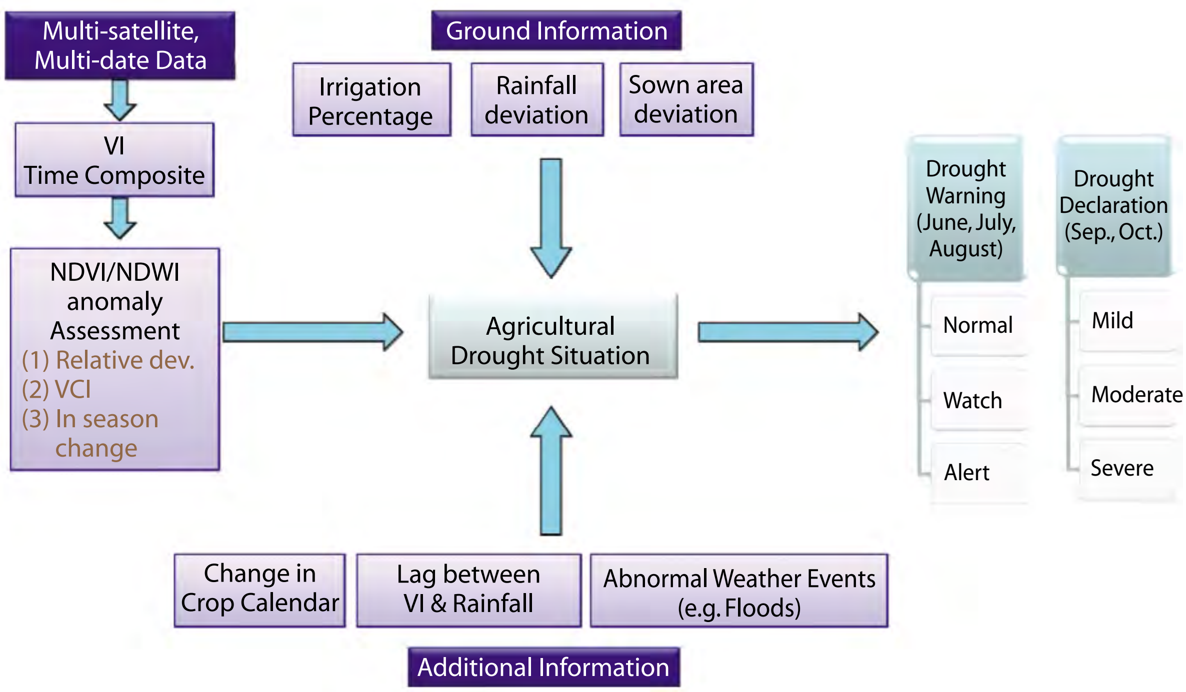
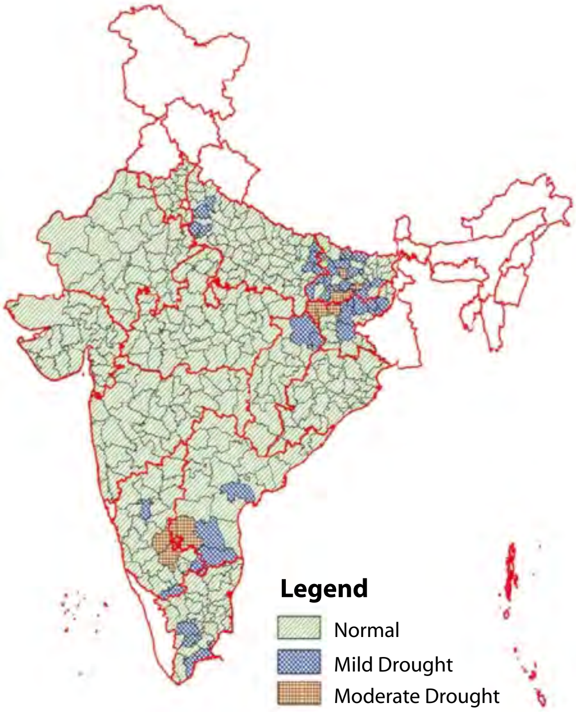


Figure 6. Methodology for drought assessment under NADAMS project

Agricultural Drought Assessment for September 2013



(No. of Districts)

State	Normal	Mild	Moderate
Andhra Pradesh	18	3	1
Bihar	16	16	5
Chhattisgart	13	2	0
Gujarat	25	0	0
Haryana	20	0	0
Jharkhand	12	7	3
Karnataka	25	3	2
Maharashtra	34	0	0
Madhya Pradesh	45	0	0
Odisha	30	0	0
Rajasthan	32	0	0
Tamil Nadu	26	4	0
Uttar Pradesh	61	8	0
Total	357	43	11

Figure 7. District level drought assessment during September, 2013 under NADAMS project

3.2 Rice flooded area mapping

Another study was carried out to assess the impact of floods on the rice crop in Odisha State of India, post-Phailin cyclone of 12 October 2013. A RISAT SAR-derived rice map was integrated with a flood inundation map developed by the National Remote Sensing Centre to map the areas of rice crop under flood. A total ten districts were affected by cyclone and rice inundation; more than 4 percent of the rice area. In four districts, namely Baleshwar, Bhadrak, Kendrapara and Jajpur, more than 15 percent of the rice was severely affected by cyclone. A post-analysis ground truth was conducted which showed the accuracy of the rice flooded area mapping was 89 percent.

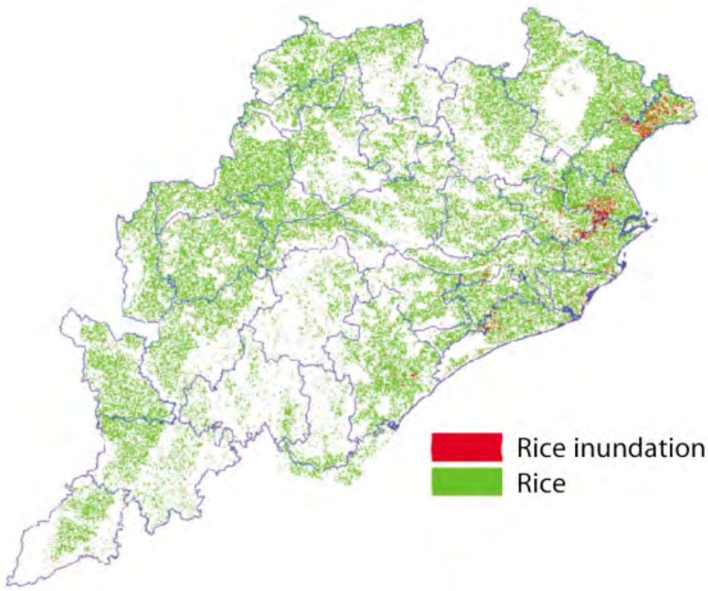


Figure 8. Flooded rice area mapping in Odisha state of Indian post-Phailin cyclone

3.3 Rabi season crop alert

As mentioned earlier, the drought assessment is generally carried out during the kharif (rainy) season. Though the majority of the crop growing area in the rabi (winter) season is irrigated, it is essential to monitor the agricultural conditions to identify any alert situation for necessary intervention measures. The crop condition was assessed using MODIS Vegetation Indices 16-Day Composite data and MODIS Land Surface Temperature 8-day Composite data. Vegetation Condition Index of NDVI and NDWI and Temperature Condition Index (Kogan, 1995) were derived using the past ten years' satellite data. Based on the above three mentioned parameters, and by using a logical modeling approach, the districts were divided into normal, watch and alert. This exercise was carried out for 8 states namely Bihar, Haryana, Punjab, Rajasthan, Uttar Pradesh, Madhya Pradesh and West Bengal (Figure 9). The analysis showed that the crop situation was normal during the rabi season of 2013-2014.

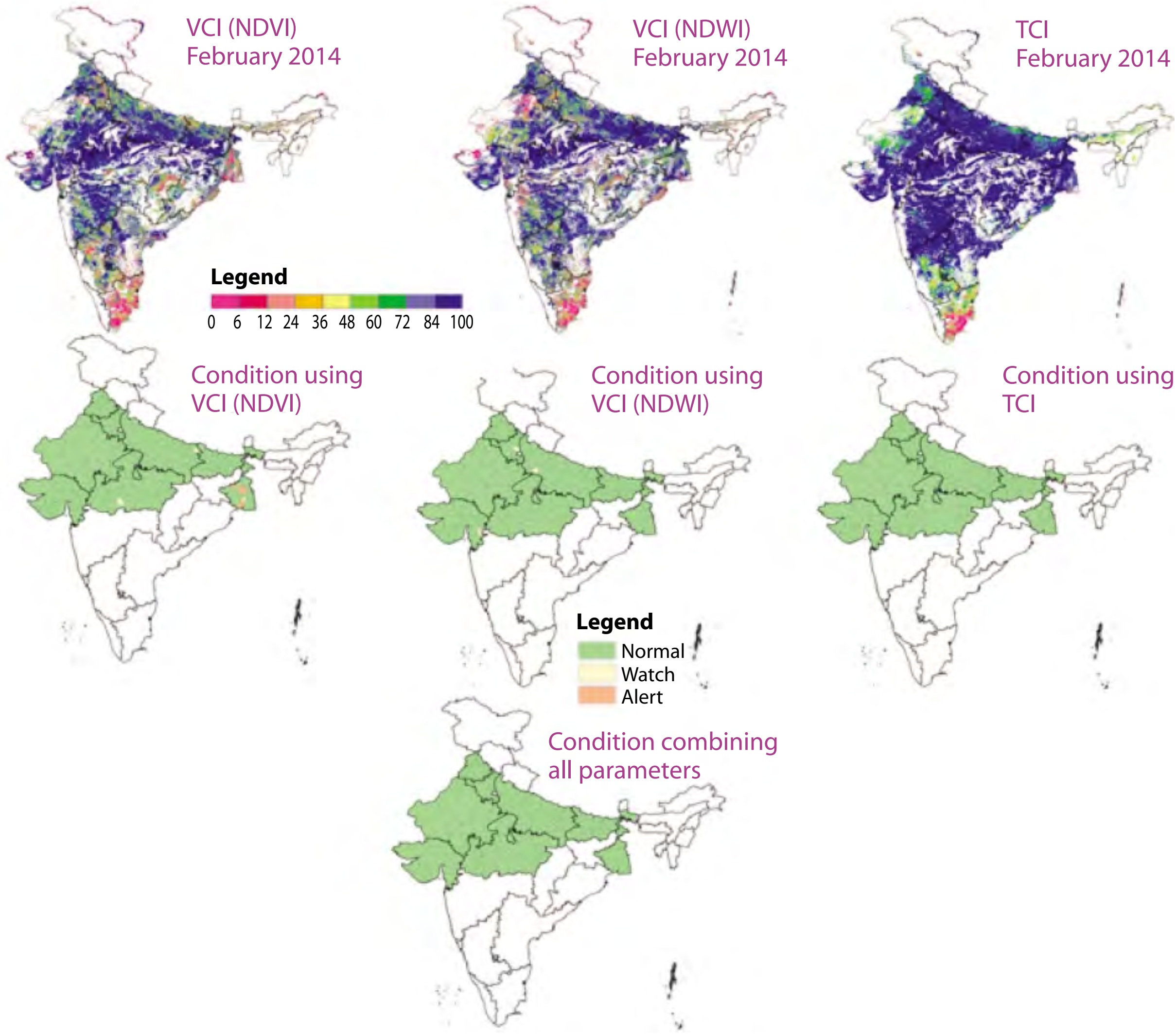


Figure 9. Rabi season crop alert assessment for 8 states of India during February, 2014

4. Conclusions

The examples presented in this article have showed how remote sensing data from various sources, in combination with other ancillary data, have been successfully used for operational assessment of agriculture in the country. However, there is a need to further extend the area of activity. The following future developments are envisaged in this field: i) taking up more crops and covering more States; ii) developing spectral yield models for all crops; iii) assessing biotic and abiotic disaster impacts on agriculture; iv) monitoring the impact of agricultural development programmes of the country; v) horticultural assessment; and vii) agricultural resources management.

Acknowledgements

The authors are grateful to the scientists of the Indian Space Research Organization for developing the procedures for the FASAL and NADAMS Projects and transferring the technology to the Mahalanobis National Crop Forecast Centre for their operationalization. The Ministry of Agriculture has not only funded this activity, but also has been responsible for the growth remote sensing applications in the country by pro-actively adopting the technology. The authors are also grateful to Sh. Ashish Bahuguna, the Secretary, DAC, for his guidance. Thanks are due to Dr. J.S. Parihar, Outstanding Scientist, Space Applications Centre and Dr. Dalip Singh, Additional Statistical Adviser, DES for their strong support to these activities.

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Remote sensing-based crop yield monitoring and forecasting

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Key words: Crop Yield Monitoring, Crop Yield Forecast, Remote Sensing, Synthetic Aperture Radar (SAR), Crop Growth Modeling, ORYZA2000

ABSTRACT

Accurate and timely information on rice crop growth and yield helps governments and other stakeholders to adapt their economic policies, enables relief organizations to better anticipate and coordinate relief efforts in the wake of a natural catastrophe, and provides technical backbone of an insurance solution where risks of yield losses from the rice smallholders are transferred to the insurance market. Such delivery of rice growth and yield information is made possible by regular earth observation using space-born Synthetic Aperture Radar (SAR) technology combined with crop modeling approach to estimate and forecast yield. Radar-based remote sensing is capable of observing rice vegetation growth irrespective of cloud coverage, an important feature given that in incidences of flooding the sky is often cloud-covered. Rice yield forecast is based on a crop growth simulation model using a combination of real-time and historical weather data and SAR-derived key information such as start of growing season and leaf growth rate. Results from pilot study sites in South and Southeast Asian countries suggest that incorporation of remote sensing data (SAR) into a process-based crop model improves yield estimation for actual yields and thus offers potential application of such system in a crop insurance program. Remote-sensing data assimilation into crop models effectively capture responses of rice crops to environmental conditions over large spatial coverage, otherwise practically impossible to achieve with a crop modeling approach alone. This study demonstrates the two angles of uncertainties reduction in forecasting crop yield: 1) minimizing model uncertainties, in this case by assimilation of remote-sensing data into a crop model to recalibrate model parameters based on remotely sensed crop status on the ground; and 2) minimizing uncertainties in seasonal weather conditions by incorporating real-time throughout the forecasting dates.

1. Background

Climatic events such as flood and drought are major threats to food security, especially in developing countries and countries with emerging economies. About 20 million hectares of rice – the staple food of most of the world's poor – are vulnerable to such climatic events. Innovative tools are needed to mitigate such risks encountered by rice smallholder farmers. Crop insurance can cover farmers' shortfall in production due to natural catastrophes. However, agricultural production is hard to insure because assessment of production loss, among others, is difficult and costly. Many crop insurance schemes implemented in the past have not been sustainable and crop insurance markets in developing countries and emerging economies continue to be under-developed. A timely rice information system linked to a crop insurance model is essential.

Remote Sensing-based Information and Insurance for Crops in Emerging Economies (RIICE, riice.org) is a public-private partnership project aiming to reduce the vulnerability of rice smallholder farmers in low-income Asian countries using synthetic aperture radar (SAR) technology. SAR data is used to map and observe rice growth, and together with a crop growth model, the technology allows prediction of rice yield in selected rice-growing regions in Cambodia, India, Indonesia, Thailand, the Philippines and Viet Nam. The use of SAR technology is crucial given cloud obstruction views from space are a common phenomena for the region where rice is grown in the tropics due to cloud-insensitive features of radar-based earth observation. National partners in the countries covered by RIICE provide expert knowledge and baseline data, and conduct fieldwork and monitoring of sites. This paper describes the progress of the RIICE project specifically in the technical aspects of remote sensing and crop yield estimation.

2. Methodology

The remote sensing-based rice yield estimation system involves two key modules: 1) MAPscape-RICE; and 2) ORYZA2000 (Figure 1). MAPscape-RICE is the interface from satellite-based observation data into SAR products such as rice area estimates, start of season (SoS), phenological field status, and leaf area index (LAI). The system assimilates SAR products, namely LAI and SoS, into ORYZA2000 in order to generate yield estimates. Combined with rice area product, the estimated yield then can be converted into production estimates for the selected geographical area.

2.1 Remote sensing-based rice products

The rice extent/area (extent, 1 ha/area, 15 m) based on archive ENVISAT ASAR data represents the location and the total multi-annual and/or annual extent/area. This product, which is essential when historical rice maps are not available, is generated using multi-year or annual ASAR WS archive data (100 m) and/or high resolution SAR data such as ASAR AP/IM and PALSAR FBS/FBD data (15 m). Omitting temporal outliers, the SAR time-series data for a given time frame (for instance weekly), are temporally averaged and, after the derivation of selected temporal features (such as minimum, maximum, range, minimum and maximum increase/decrease), mapped as rice using a knowledge-based classifier.

Multi-year ENVISAT ASAR WS (400 x 400 km, 100 m) and multi-year/annual IM/AP archive C-band data (100 x 100 km, 15 m) have been processed to generate Multi-year and Annual Rice Extent/Area. Moreover, exclusively for the Philippines, archive ALOS PALSAR-1 FBD L-band data (70 x 70 km, 15 m) have been used. Concerning archive SAR data, it is worth mentioning that, in general, South-East Asia has been well covered during the ENVISAT ASAR mission, in particular in the WS mode.

Dedicated multi-temporal Cosmo-SkyMed (40 x 40 km, 3 m) X-band acquisitions are regularly carried out (approximately every 16 days) over selected areas according to the local rice crop calendars. So far, in most of the countries, two crop seasons have been covered using Cosmo-SkyMed. In those areas, contemporaneously to the SAR acquisitions, national partners are conducting ground observations for correlating SAR products with actual ground conditions; this includes monitoring or rice phenology, measurement of LAI, and validation of rice area product.

SAR data processing is initiated by acquisition planning to select the most suitable geometries, modes, and proper crop season period. In the next step, Single Look Complex (SLC) data are transformed – in a fully automated way – into terrain geocoded backscattering coefficient by means of: 1) generation of strip mosaics of single frames in slant range geometry and multi-looking; 2) grouping of the strip mosaics acquired with the same geometry; 3) Digital Elevation Model (DEM)-based orbital correction; 4) co-registration; 5) De Grandi time series speckle filtering; 6) terrain geocoding, radiometric calibration and normalisation; 7) Anisotropic Non-Linear Diffusion (ANLD) filtering; and 8) removal of cloud-related effects. Subsequently, dedicated remote sensing products are generated which in turn are used within the crop growth simulation model to estimate yield.

Due to the large amount of the remote sensing data and the time consuming processing, the SAR processing is performed using a high performing cluster solution, where a master PC coordinates processing PCs and supervises the overall processing. Each processing PC is equipped with a CPU with parallel processors or GPU. Note that: 1) all MAPscape-RICE algorithms have been implemented to fully exploit the processor characteristics; and 2) the cluster can be extended according to the amount of data and/or requested product generation time.

When SAR data time-series are acquired on a regular basis and tuned according to the rice season period and crop practices, then information on not only the rice area but also when and where fields are prepared and irrigated, the phenological rice field status – such as flowering, tillering, plant senescence and harvesting – and related dates of irrigation, peak of rice season, and harvesting can all be detected. These are crucial spatial-phenological inputs for an accurate rice growth modeling. These products are generated based on the well known temporal relationship between the radar backscatter and the rice phenology, by considering not only the different wavelengths and polarizations, but also crop practices and seasonal lengths.

LAI is defined as the one-sided green leaf area per unit ground area and for rice it ranges between values close to zero for seedlings to a maximum of 10–12 at flowering, although maximum values closer to 6 or 7 are typical. In this rice yield estimation system, LAI is inferred from the backscattering coefficient by means of the vegetation water cloud model (Attema and Ulaby 1978).

Flood or drought-affected areas can be identified if appropriate time-series data at the time of the event are available. In both cases, in general, a significant decrease of the backscattering coefficient is observed. However, the cause and nature of the decrease are different: in case of flooding, a sharp decrease is observed and is due to the dominant water surface scattering, while plant moisture loss – or drought – is observed through a continuous radar backscatter decrease.

2.2 Rice yield estimation by modeling

Rice yield estimation is based on a Crop Growth Simulation Model (CGSM) of ORYZA2000 (Boumman *et al*. 2001). In order to consider soil nitrogen dynamic processes, the CGSM uses soil data (https://sites.google.com/a/irri.org/oryza2000/) extracted from the World Inventory of Soil Emission potential (WISE) dataset (http://www.icasa.net/toolkit/wise.htm) and Harmonized World Soil Database (HWSD) (http://webarchive.iiasa.ac.at). Some assumptions on puddling effect on physical soil properties have been made. Weather data are obtained from NASA Power dataset (http://power.larc.nasa.gov). These are subsequently corrected based on reported values from local weather stations (http://www.ncdc.noaa.gov) and down-scaled to 15 arc-minutes resolution (Sparks *et al*. unpublished) for daily solar radiation, daily minimum and maximum temperature, vapor pressure at minimum temperature, and daily average wind speed, and from the Tropical Rainfall Measurement Mission (http://trmm.gsfc.nasa.gov) for daily rainfall data.

The simulations account for water and nitrogen dynamics based on climate, soil conditions and management rice practices. Irrigation and nitrogen fertilizer inputs are assumed as recommended for achieving attainable yield. LAI values – 50 days after emergence and provided by the SoS product – are inferred from radar backscatter using cloud vegetation model (Attema and Ulaby 1978) with parameters calibrated with *in situ* LAI measurements. Inferred LAI are finally used to calibrate the relative leaf growth rates parameters in ORYZA2000. For processing efficiency, the spatial units for yield simulation are aggregated to 180 meter resolution.

Yield forecast is based on a series of simulations using weather data sets combining real-time weather and historical weather data and conducted on a weekly basis. The assimilation of SAR products begins after at least 4 cycles of SAR data have been acquired since the onset of rice season period in the area (land-preparation). Beginning from 35 days after crop establishment, SAR product assimilation into the crop forecasting system is implemented. During this early part of the rice growing cycle, leaf expansion parameters can be effectively calibrated against real ground conditions inferred from satellite observation using radar technology.

3. Results

Multi-year rice area products, as illustrated in Figure 2a and 2b, have been generated. In general, based on several field visits, the products have a good accuracy in areas where rice fields are homogeneous, while lower (expected due to the ASAR data availability) accuracies have been observed in those areas where the fields are scattered, fragmented, and heterogeneous.

Three geographical areas – Nueva Ecija in Central Luzon, Leyte in the Visayas and Agusan del Norte in Mindanao, Philippines – characterized by different field dimensions and rice practices have been acquired using Cosmo-SkyMed SM and ScanSAR during three crop seasons. Some products examples are shown in Figure 2b and 3.

The well populated ASAR WS and IM data archive in the geographical area in the Red River Delta, Viet Nam combined with the large and homogeneous rice fields in both seasons means that very accurate Multi-year Rice Extent and Annual Rice Area products, could be generated as illustrated in Figure 4 (left panel). Moreover, the use of very high resolution Cosmo-SkyMed SM data acquired every 16 days resulted in a detailed phenological monitoring at field level for each rice season, as shown in Figure 4 (right panel). Land cover category boundaries have been provided by NIAPP.

Due to the rice maturity type characteristics in Cambodia, i.e. short and medium-long duration, we opted to acquire Cosmo-SkyMed SM time-series during 7 months at 16 days interval. As an example, Figure 5 illustrates short duration rice in green and medium duration rice in yellow. Differentiation between the two was confirmed though a field visit carried out in the middle of the season.

In the Cauvary Delta region in Tamil Nadu, India, a dedicated ASAR IM planning was carried out in 2011. Even though not all planned data were delivered, it was possible to develop an Annual Rice Area product, as shown in Figure 6 (left panel). The main challenge in this area is that rice is cultivated with several other crop types, which, at C-band, at some growth stages have a similar signature to rice. It is therefore important to supplement the area estimates with multi-temporal SAR data according to known locally varying rice calendars. This strategy was adopted over three sites by using Cosmo-SkyMed SM time-series during 5 months at 16 days interval with results shown in Figure 6 (right panel).

In the Philippines, more extensive assessments have been made for the integration of LAI from SAR intensity data and the ORYZA2000 crop growth model. Table 1 provides validation at the 2nd administrative level (below the provincial level) with respect to the estimated rice yield against observed rice field from crop cutting experiments (CCE) in Leyte, Philippines. On average, compared to the observed yield, the accuracy is 85 percent with a Root Mean Square Error (RMSE) of 702 kg ha^{-1}. In Agusan Del Norte, ex-ante yield estimation (forecast) has also been tested as shown in Figure 7. Yield forecast was improved with the incorporation of SAR products since 35 days after crop establishment.

4. Conclusions

Lowland rice cultivation is the land use type showing the largest spatial and temporal dynamic in both vegetation and water during a short period (3 to 6 months). Reliable remote sensing-based rice area and rice crop status information requires a combination of good spatial and temporal resolution in a way that both dynamics are fully captured. Moreover, spatial and temporal seasonality and status information from remote sensing are key inputs for crop modeling to capture the spatial variability in yield and production across broad geographic extents that cannot be easily captured in any other way. The RIICE service is being applied in seven Asian countries and it is under validation and evaluation by the national partners.

5. Success achieved and issues for further research

The use of the existing ASAR WS and IM/AP archive data, even if not optimal for the targeted application, provides a valuable data source, enabling the generation of a consistent rice extent/area product over 1.5 million km^2. It is therefore strongly recommended to the space agencies that future SAR missions such as Sentinel-1A/B should incorporate systematic background missions according to the geographical areas and applications instead of building data archives according to sporadic user requests.

Multi-temporal data is fundamental from a data processing and analysis perspective. Few or sporadically acquired images are of little use for operational mapping and monitoring. Systematic acquisitions of remote sensing data at different spatial resolutions – from 3–5 m, 10–20 m, and 100–250 m at different wavelengths is essential for agricultural applications. In particular, the near future availability of Sentinel-1A/B, -2 and -3 combined with MODIS and very high resolution SAR data (Cosmo-SkyMed and TerraSAR-X StripMap mode) will enable country-wide provision of reliable cultivated area that would capture even small plot agriculture (Holecz *et al.* 2013) and the corresponding phenological monitoring.

As demonstrated in this paper, the spatial resolution of existing spaceborne remote sensing systems and the wise integration of different remote sensing sources enable us to achieve a high level of detail and accuracy, whenever the data are understood, processed and used in the right way. Doubtless, the proposed solution is attractive, less time consuming and less expensive compared to area regression estimators exclusively based on field surveys. Furthermore, the remote sensing solution provides a monitoring component; this is often not taken into account in the area regression estimator approach, simply because it is too time consuming to frequently repeat the field surveys.

It has been demonstrated that the incorporation of dedicated remote sensing products into the yield crop model is essential. This enables the system to: 1) capture the plants response to otherwise inestimable environmental conditions over large areas; 2) include relevant information on rice phenology to initialize the crop model on the correct date; 3) consider the spatial distribution of rice fields so that yield estimates are only made where rice is cultivated that season; 4) improve overall yield estimation figures by calibrating the model to actual yields rather than theoretical attainable or potential yields.

National partner involvement is crucial as the only way to sustain, promote and validate the need for in-country, operational crop monitoring. In RIICE, national partners lead the terrestrial data collection and validation, but also contribute to product generation, where the knowledge on the rice types and practices is essential. For this reason RIICE incorporates an intensive technology transfer to the national partners and applications of remote sensing-based information for food security and crop insurance applications at national/government level.

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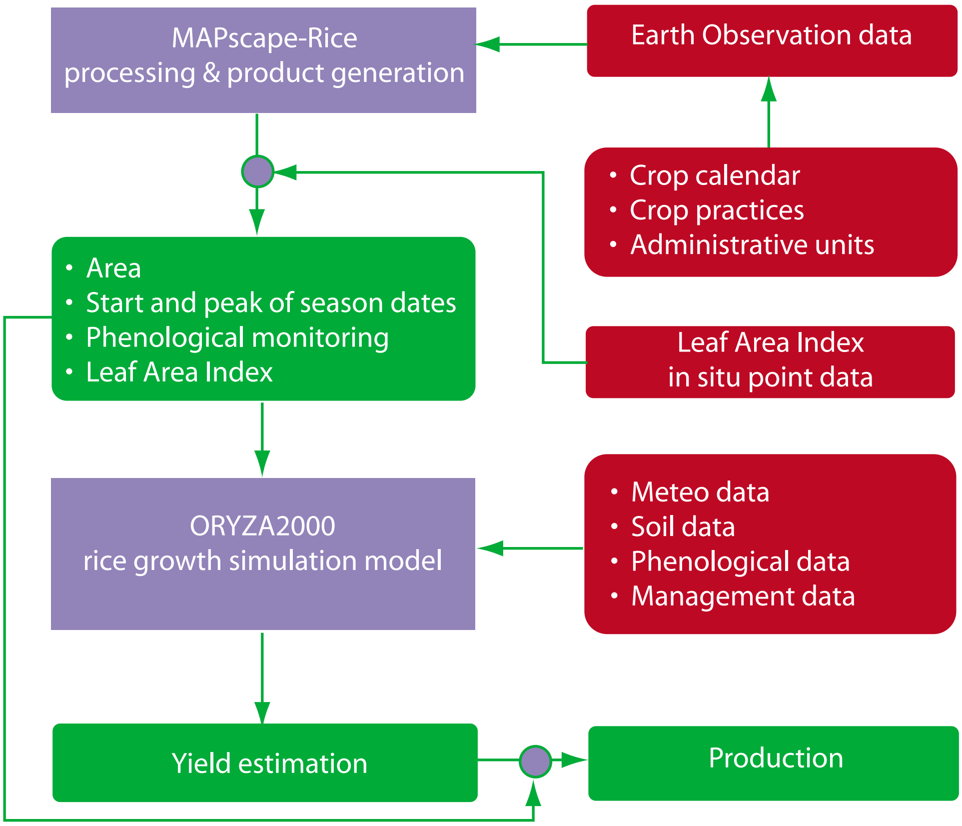

Figure 1. RIICE yield and production estimation system involving MAPScape-RICE for SAR products generation and ORYZA2000 version configured to interface with remote sensing products.

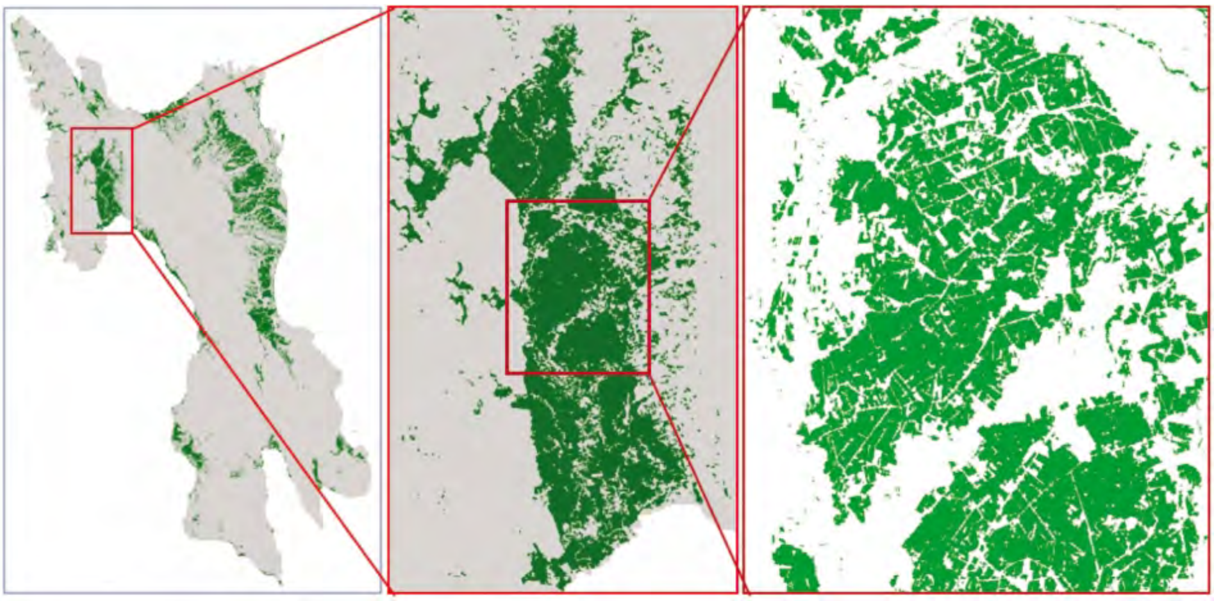

Figure 2. (a & b) The rice extent map of Leyte at 1-ha resolution derived from ASAR wide swath images acquired from 2004 to 2012; (c) single season rice area product generated from 3 m CSK data acquired from June to September 2012.© Cosmo-SkyMed data ASI distributed by e-GEOS, processed using MAPscape-RICE.

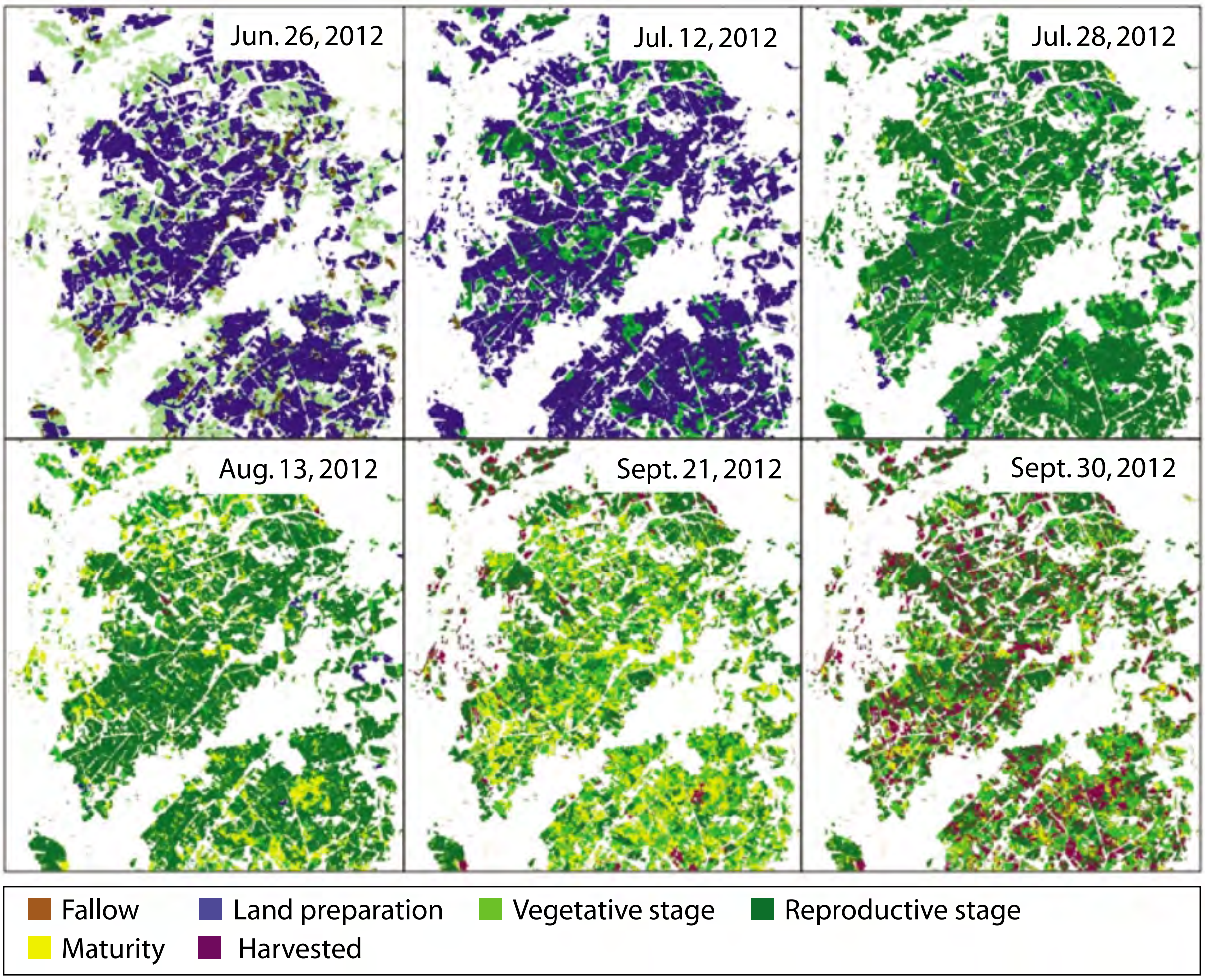

Figure 3. The phenology of rice field during the wet season of 2012 in Leyte, Philippines as inferred from SAR product. © Cosmo-SkyMed data ASI distributed by e-GEOS, processed using MAPscape-RICE

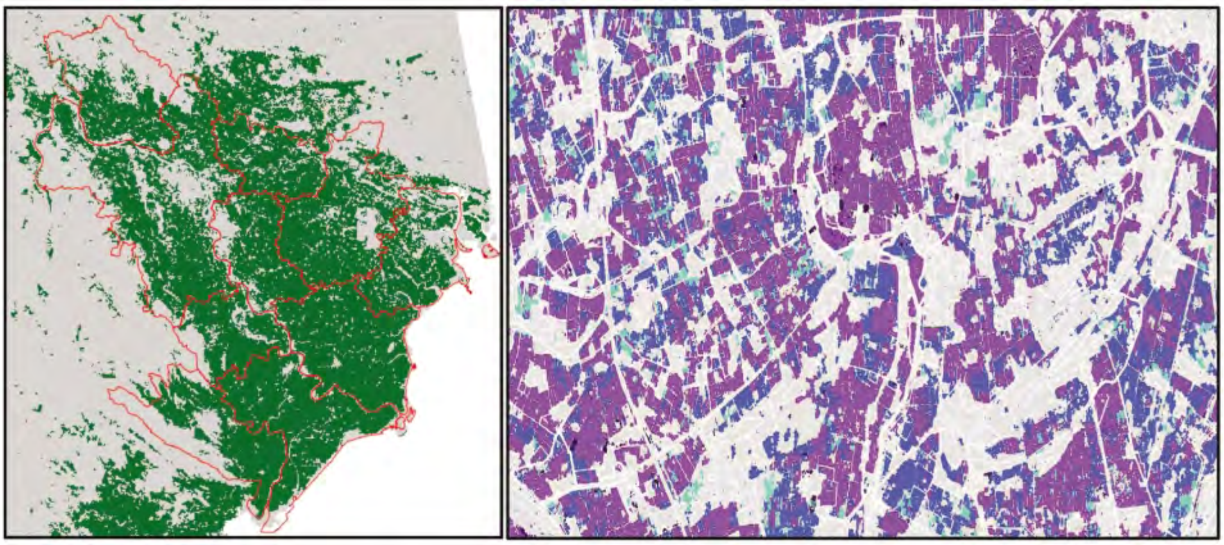

Figure 4. Rice extent (1 ha) based on ASAR WS archive data acquired from 2003 to 2010 (left panel) and seasonal rice area at 3 m for a sample area based on Cosmo-SykMed Strip Map mode (SM) in Red River Delta, Viet Nam from January to May 2013 (right panel). The different colors correspond to the different dates of start of season (SoS). © Cosmo-SkyMed data ASI distributed by e-GEOS, processed using MAPscape-RICE.

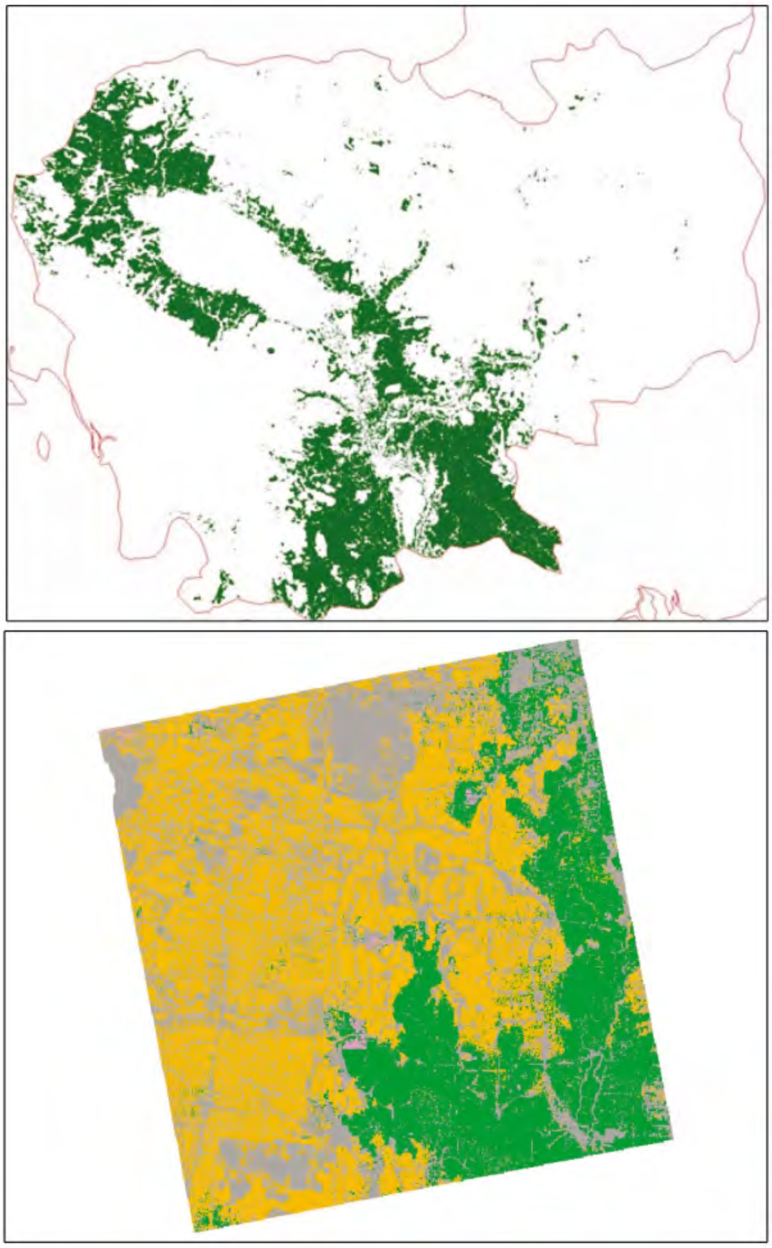

Figure 5. Rice extent (1 ha) in Cambodia based on ASAR WS archive data acquired from 2005 to 2010 (left panel). Seasonal rice area (3 m) for short duration (green) and medium-long duration (green) in sample area near Takeo, Cambodia based on Cosmo-SkyMed SM acquired from September 2012 to March 2013. The different colors correspond to the different dates of start of season (SoS). © Cosmo-SkyMed data ASI distributed by e-GEOS, processed using MAPscape-RICE.

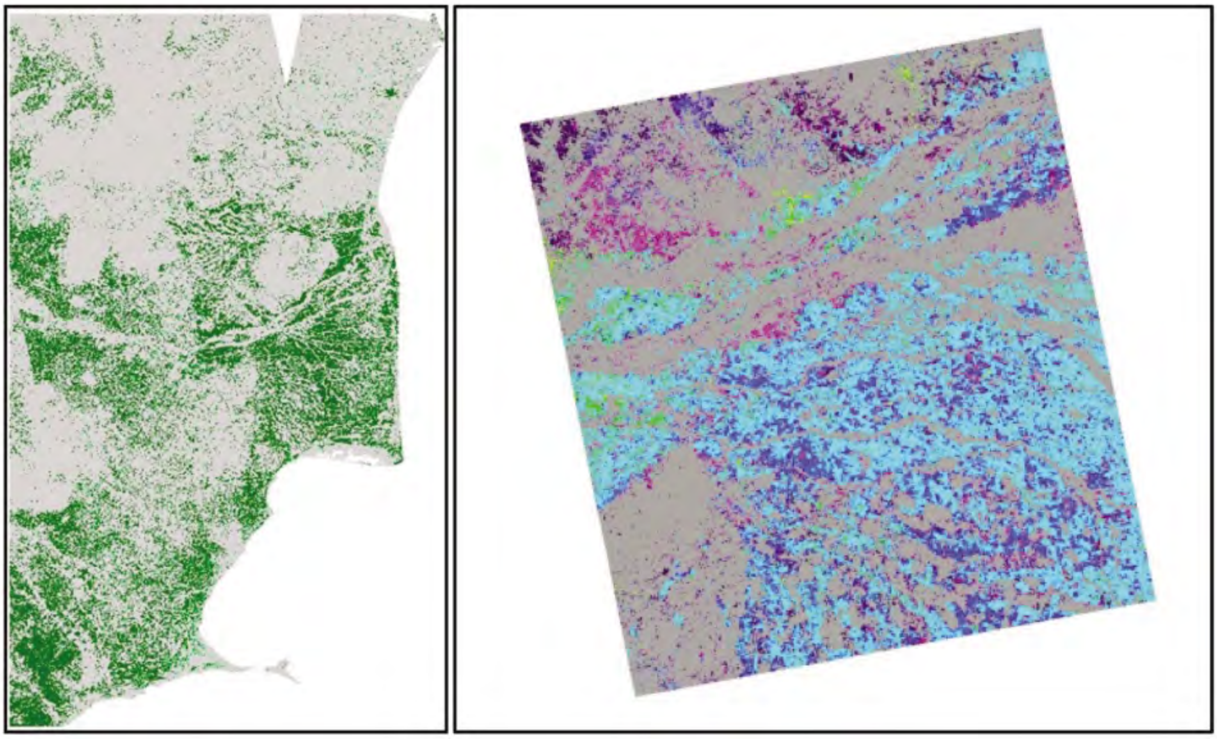

Figure 6. Rice area (15 m) based on ASAR IM data acquired during 2011 in Cauvary Delta and surrounding area in Tamil Nadu, India (left panel) and seasonal rice area at 3 m for a sample area near Thanjavur, Tamil Nadu, India based on Cosmo-SkyMed (SM) data acquired from September 2012 to February 2013. The different colors correspond to the different dates of start of season (SoS). © Cosmo-SkyMed data ASI distributed by e-GEOS, processed using MAPscape-RICE.

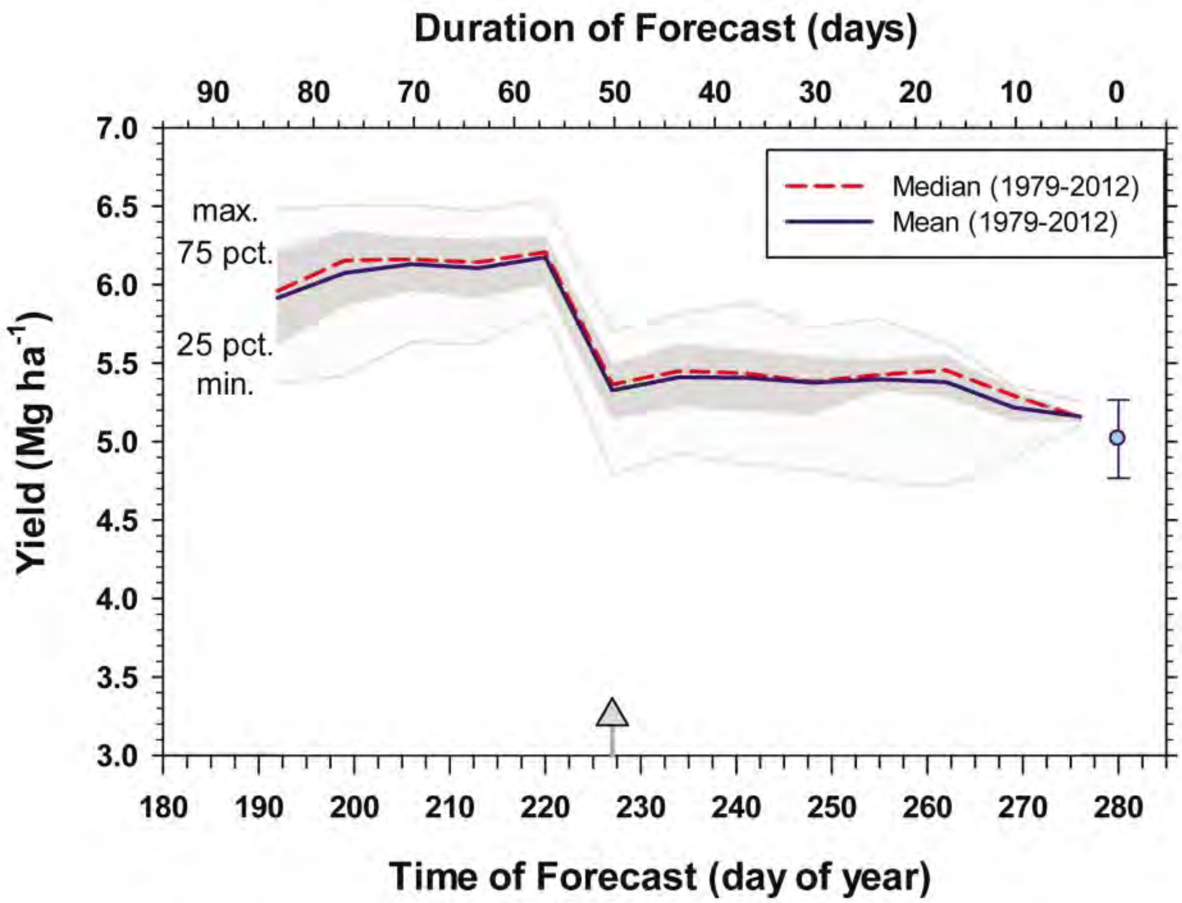

Figure 7. Weekly yield forecast for one of the RIICE pilot field sites in Agusan del Norte, Philippines in wet season 2012. Arrow on day 227 marks the start of SAR data assimilation with the yield estimation system. Symbol and error bar on day 280 indicates actual yield and standard error obtained from crop cut experiment in farmer's field involving 4 replications. The forecast started from the day of transplanting (day 192).

Table 1. Validation of RS-based rice yield estimates for RIICE study site in Leyte, Philippines in wet season 2012

Administrative unit	Yield (Mg ha^{-1})	
	Observed Yield[1]	Estimated Yield[2]
Amahit	2.96	1.94
Cuta	3.79	4.32
Liloan	5.96	5.04
Maticaa	5.14	5.69
Sabang Bao	4.99	4.94

RMSE (kg ha^{-1}) = 702
Accuracy (%) = 85

[1] crop cutting experiment
[2] SAR products-ORYZA2000

Satellite-based crop monitoring and estimation system for food security application in Bangladesh

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ABSTRACT

Food security is an increasingly important issue for Bangladesh, which is under high demographic pressure and climatic disturbances due to global warming, climate change phenomena, etc. together with acute land resource constraints. 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 on a large scale, on a repetitive basis. Proper utilization of such technology is to be ensured to provide necessary information support to the national food security program.

The Bangladesh Space Research and Remote Sensing Organization (SPARRSO), being the national focal point of remote sensing technology, has been regularly monitoring the major agricultural crops 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 conditions, discrimination of type and estimation of crop area, particularly for Aman and Boro rice in the country. Researches for monitoring of other important crops in the country are also underway at SPARRSO. A technical approach for remote sensing information retrieval through the application and analysis of derivatives of space-based radiative measurements in the spatial, temporal, angular and spectral domain is quite evident.

SPARRSO recognizes four major concerns in developing an operational crop monitoring system in Bangladesh for effective information retrieval: i) appropriate and timely satellite data; ii) effective RS algorithm-based methodology; iii) a mobile RS ground data collection platform along with a distributed observational ground network; and iv) an approach for partial automation of the associated operations and functionalities. SPARRSO has been working accordingly on the development of an integrated operational system supported by 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 devise 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 requirements considering the spatiotemporal dynamics of Earth's surface features is an on-going investigation process aimed 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 have been recognized as important inputs and have been integrated in satellite-based agricultural monitoring operation at SPARRSO.

SPARRSO is in the process of developing a Mobile RS platform supported by necessary RS instrumental facilities for ground-based observation and measurement of important biophysical parameters of crops concerning 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. The Food and Agriculture Organization of the United Nations (FAO) has been playing an important role in addressing the food security issue throughout the region for a long time.

1. Introduction

Consequences of global warming, climate change and the sea level rise phenomena have seriously affected the world. Intensification of disasters such as floods, cyclones, droughts, etc. in recent years, together with increased food demand by growing populations imposed great challenges to the safety, security and livelihood of the people. A 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. The Bangladesh Space Research and Remote Sensing Organization (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 along with intensification of disasters, shrinking of agricultural land due to a rapidly growing population, disaster-induced crop damages, etc. pose rising challenges to food security the world over. Proper management and possible remedial approaches for mitigation are 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 on a large scale on a repetitive basis. Satellite remote sensing along with ground-based RS and other geospatial technologies offer immense potential and advantages in performing useful geospatial operations and functions 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 SPARRSO. SPARRSO has been working with the objective to make contributions in monitoring major agricultural crops in the country. SPARRSO has been regularly performing the operation for agricultural crops, particularly for Aman and Boro rice monitoring in the country for the last two decades and providing important information support to the government.

2. Interaction of solar radiation and plant growth

Solar radiation interacts with plants 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 and 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 and development of a plant. Photosynthetic absorption over the life cycle is related to the growth and yield of the crop. The presence of water in the leaf is also an important criterion. Data interpretation provides information on the properties of vegetation and surface materials.

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

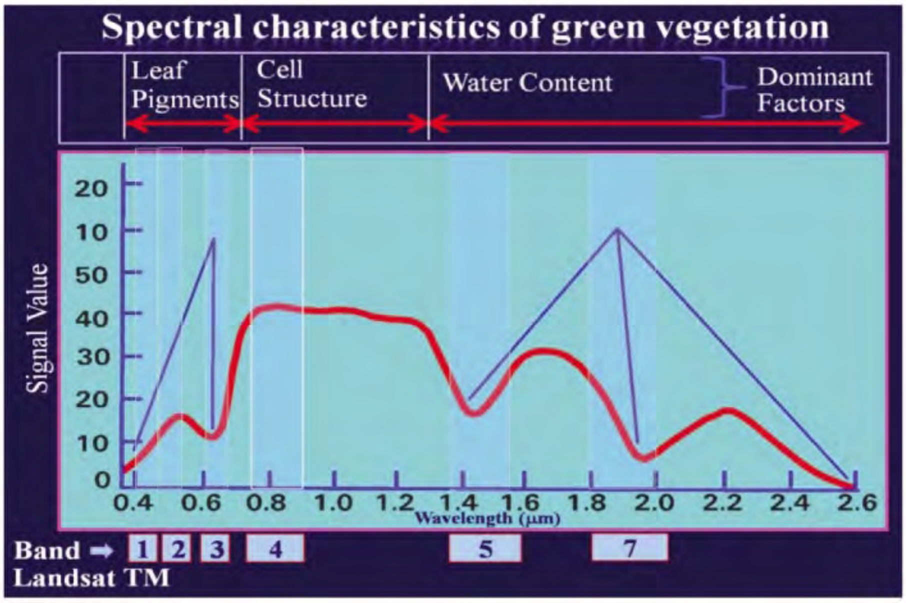

Figure 1. Spectral characteristics of green vegetation

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, and radiometric crop responses.

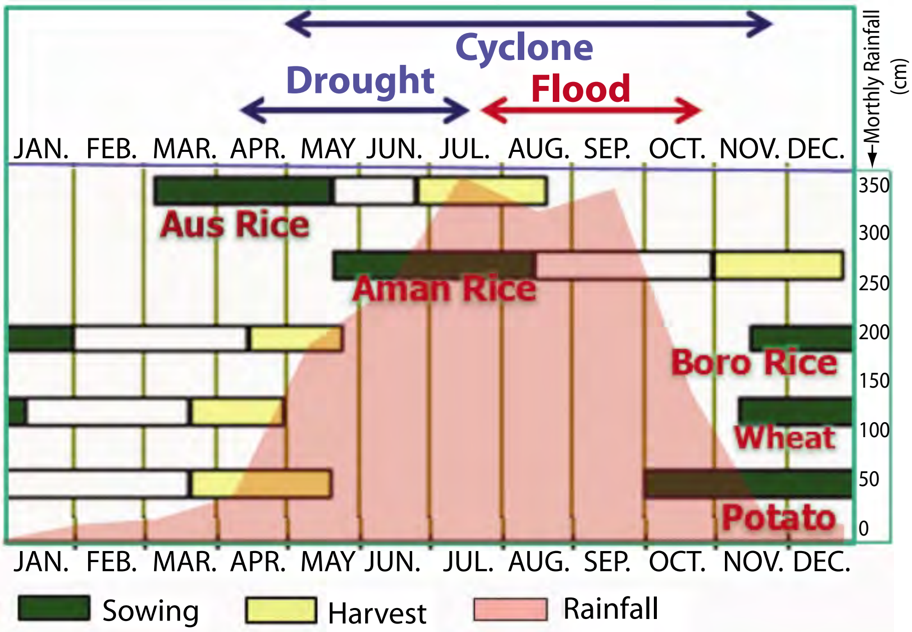

Figure 2. Calendar of major crops in Bangladesh with position of various disasters

The 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 the 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 their life cycle with the incident solar radiation and this 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).

3. Application of remote sensing (RS) technology

3.1 Basic considerations

In satellite-based remote sensing, the Earth's surface is illuminated by sunlight and a portion of the incident sunlight is reflected or emitted by the surface. The satellite sensor receives the reflected or emitted sunlight coming from the surface after interaction with the surface features. RS technology utilizes the characteristics of the received signal through necessary radiative analysis. Basically, the Earth's surface features, e.g. soil, water and vegetation have their own 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 *et al.* 2004).

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 the sun's 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, the 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.

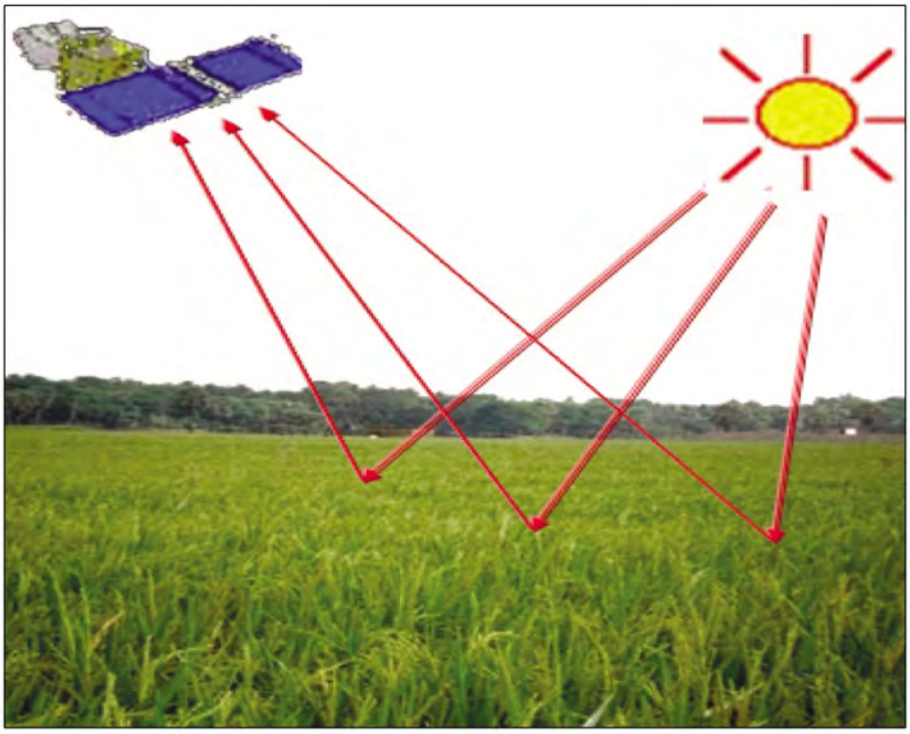

Figure 3. Geometrical configuration in a typical remote sensing system composed of illumination source (Sun), satellite, atmosphere and surface with different features. The geometrical parameters are Sun angle, viewing or observation angle and their relative azimuth angle.

3.2 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 the frequent (high temporal resolution) medium spatial resolution images provide 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 layers, e.g. forest, 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.

4. Adopted information retrieval approach at SPARRSO

4.1 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 odel 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.

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 processes, atmospheric constituents influence the radiative signal passing through the atmosphere in the double way trajectory from the sun to the surface and then the surface to the 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 corrective operations (Rahman and Dedieu 1994).

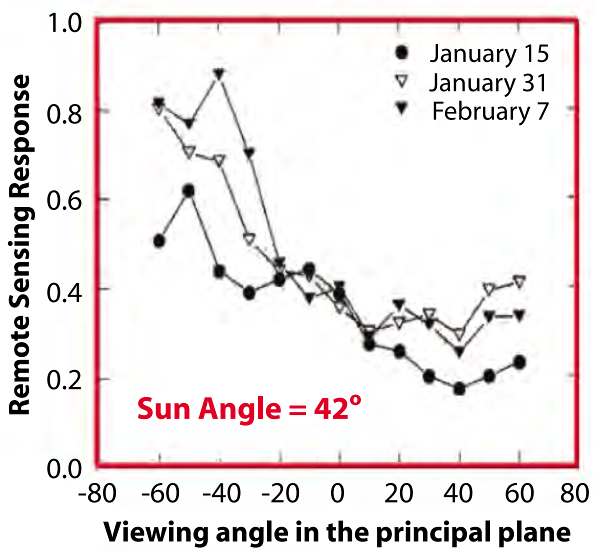

Figure 4a. Variation of remotely sensed field measured directional reflectance over a wheat crop in Sonargaon, Bangladesh at different growth stages showing dynamics of surface radiative responses of wheat crop. Measurements have been carried out by SPARRSO as a part of its research activities on agricultural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

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

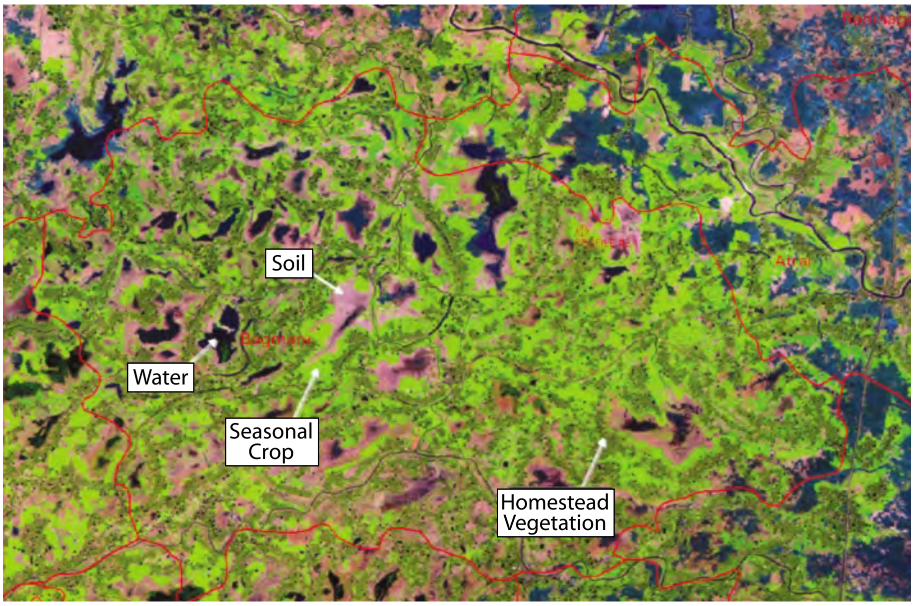

Figure 4b. Feature identification through spectral characterization of Landsat TM colour composite of 21 January 2010 Band 5, 4, 3 (RGB) (Source: SPARRSO)

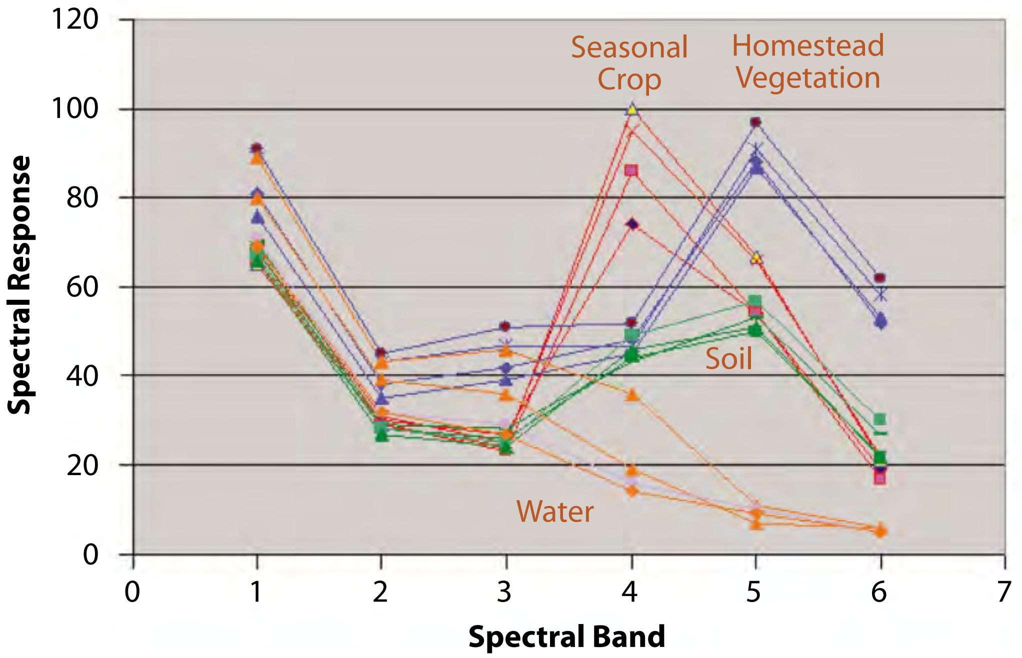

Figure 4c. Basis for spectral relational approach discriminating feature types

5. Towards operationalization of crop monitoring at SPARRSO

5.1 Crop type discrimination

The crop type discrimination process consists of analysis of temporal and spatial variability of vegetation spectral radiative responses. In such processes, amplitude and temporal variations of crop spectral response are evaluated. The logic behind it is that different crops exhibit different patterns and time phasing of their 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 technique employing a numerical modelling approach through an optimization procedure for possible solution (Weiss *et al.* 2000; Rahman *et al.* 1993a, 1993b) or through index-based operation (Sellers 1985, 1987; Gobron *et al.* 2000). In parallel, fruitful application of a crop calendar in relation to the growth rhythm of vegetation is to be made as a step for crop type discrimination.

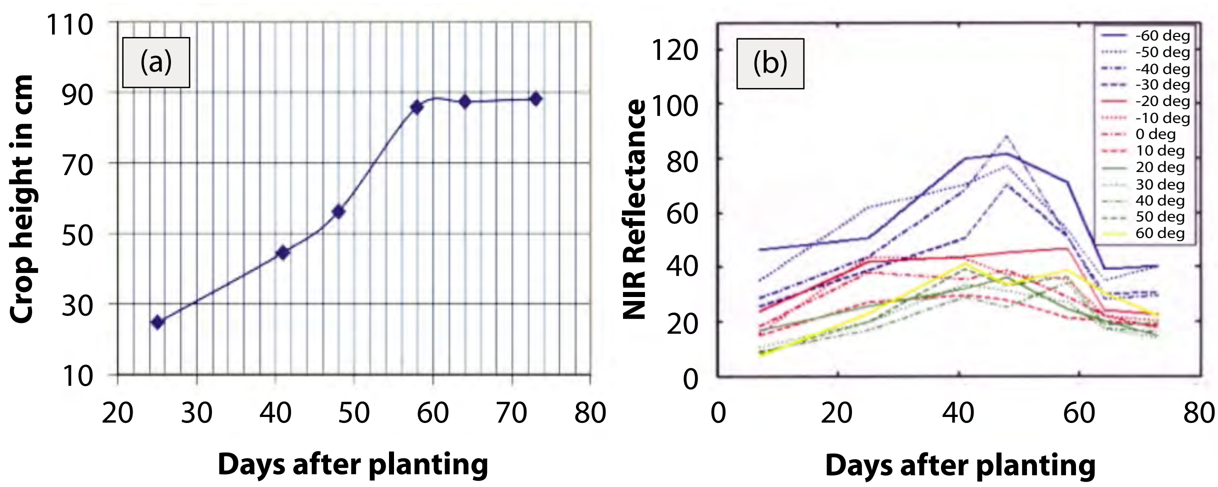

Figure 5(a). Measured variation of height of rice plant during the developing time phase, **(b)** Temporal variation of spectral response of wheat crop as a function of day after plantation over the crop life time for varying viewing angle. The study has been performed under a research work conducted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

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.

5.2 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 coordinates 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. The operation has been performed by SPARRSO as a part of implementing the agricultural monitoring program of SPARRSO.

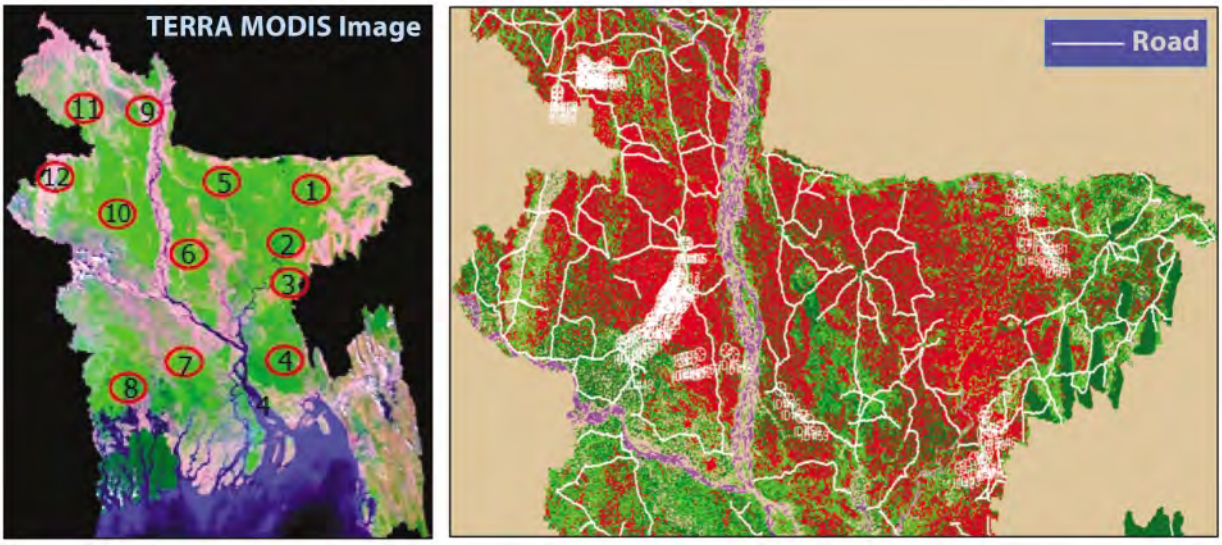

Figure 6. Ground-based profiling at selected points covering the country and measurement of biophysical parameters using various RS ground equipment along selected road network points guided by GPS. Operating has been performed by SPARRSO as a part of implementation of agricultural monitoring program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

6. Crop estimation, analysis and monitoring 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 SPARRSO using satellite remote sensing integrated with GIS and geospatial technology supported by ground-based RS biophysical measurement and observation platform. The whole system is designed by SPARRSO and is named as Crop Estimation, Analysis and Monitoring System (CEAMONS). Implementation of the whole system is under development with subsequent step-wise validation and testing operations.

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 a unique pattern and time phasing in the observed data. Such variations are generally used in retrieving information on surface cover, particularly regarding agricultural crops.

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 (Global Positioning System)-based sample field surveys are generally being carried out over stratified selected locations fairly distributed over the country. The purpose of the field survey is to support the analysis processes and to verify certain data interpretations. The rice areas are calculated by a pixel-wise analysis of radiative transfer values in the spatiotemporal domain – a methodology devised by SPARRSO.

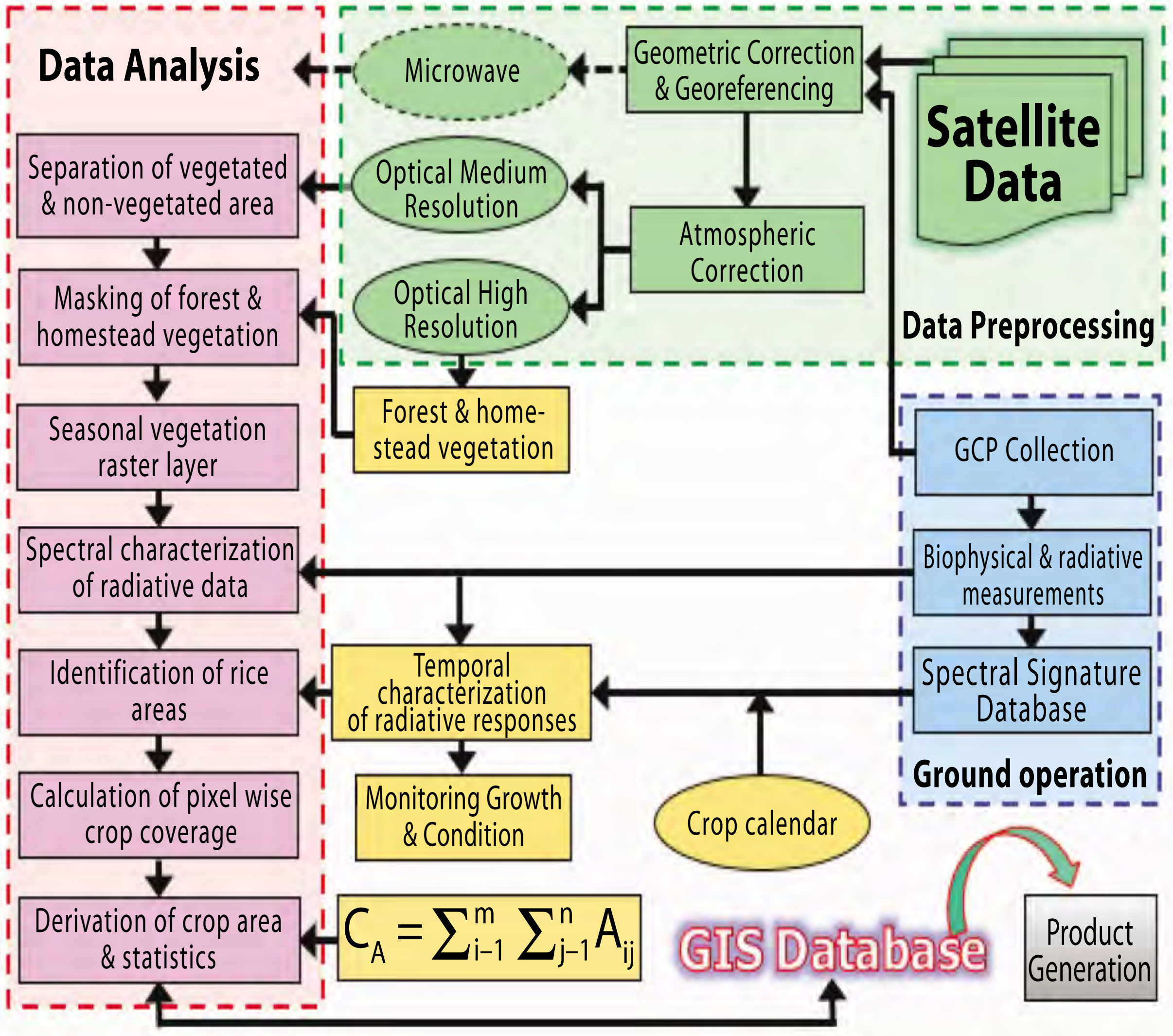

Figure 7. Algorithmic steps for crop monitoring as designed by SPARRSO using satellite remote sensing integrated with GIS and geospatial technology supported with ground-based RS biophysical measurement and observation operation. Implementation of the whole system is under way with subsequent step-wise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

6.1 Implementing CEAMONS crop monitoring algorithm at SPARRSO

The RS-GIS Agricultural Decision Support System at SPARRSO is configured with: i) a comprehensive geospatial database (satellite-borne and others); ii) an RS methodological framework with an appropriate algorithm for monitoring of major agricultural crops; iii) a protocol for time series geospatial data analysis; iv) a 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 is 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 SPARRSO.

Figure 8b shows functional block 2 comprising 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 SPARRSO.

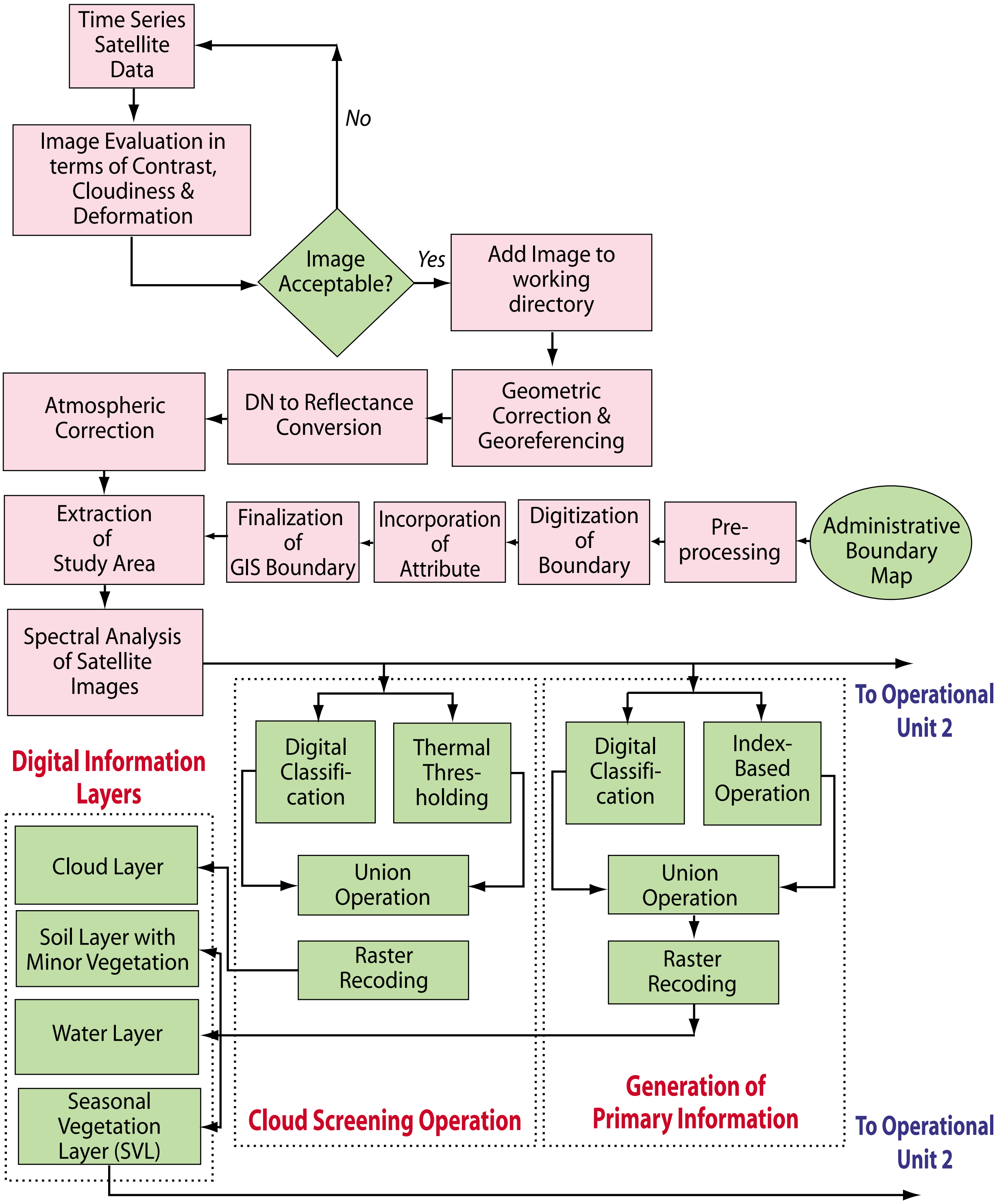

Figure 8a. Functional block 1 corrrsponding to cloud-free satellite data selected, preprocessing and generation of primary information layers for crop monitoring using satellite remote sensing by SPARRSO.

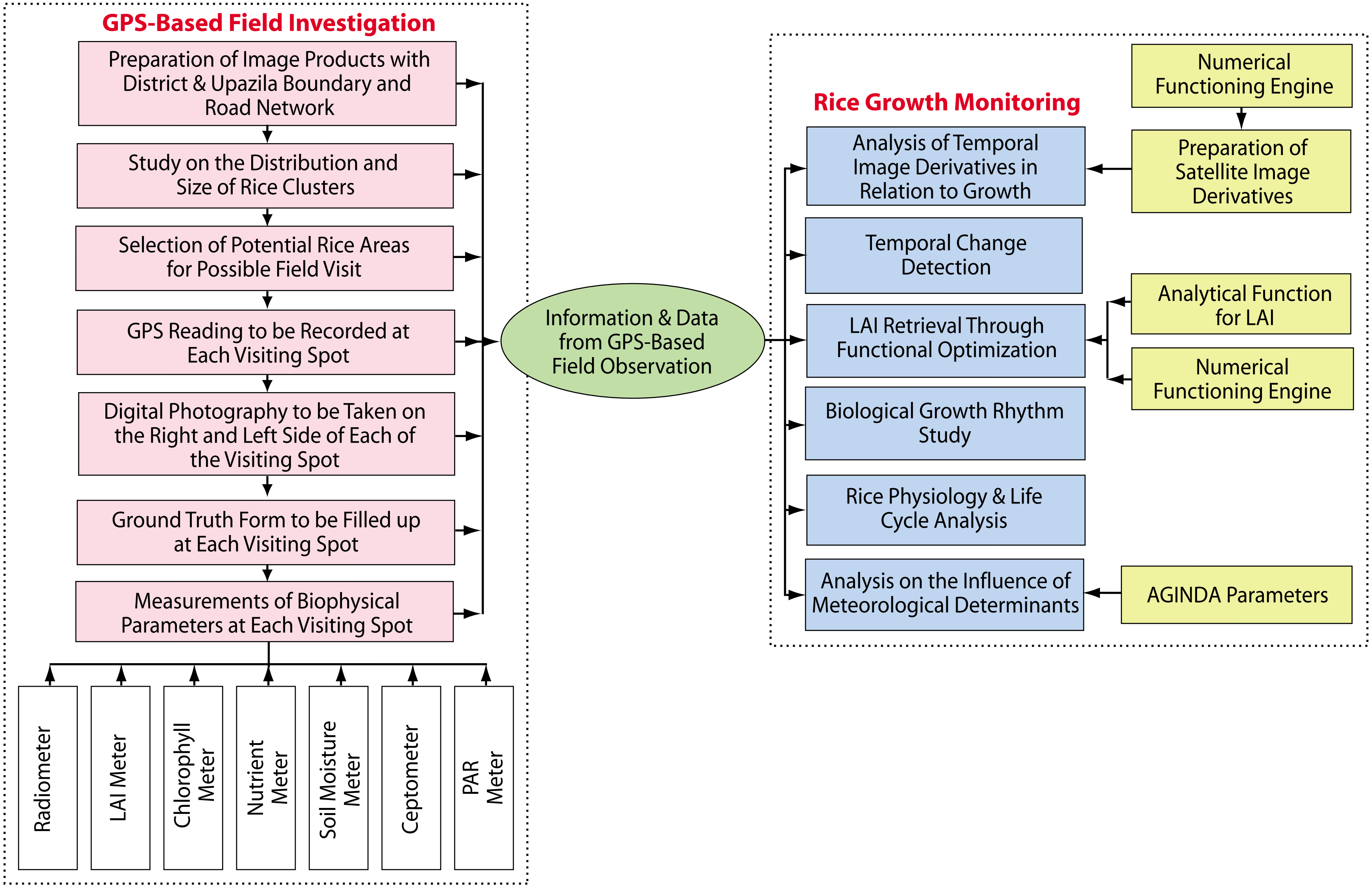

Figure 8b. Functional block 2 comprising GPS-based field investigation and satellite image-based numerical calculation and analysis operation (SPARRSO)

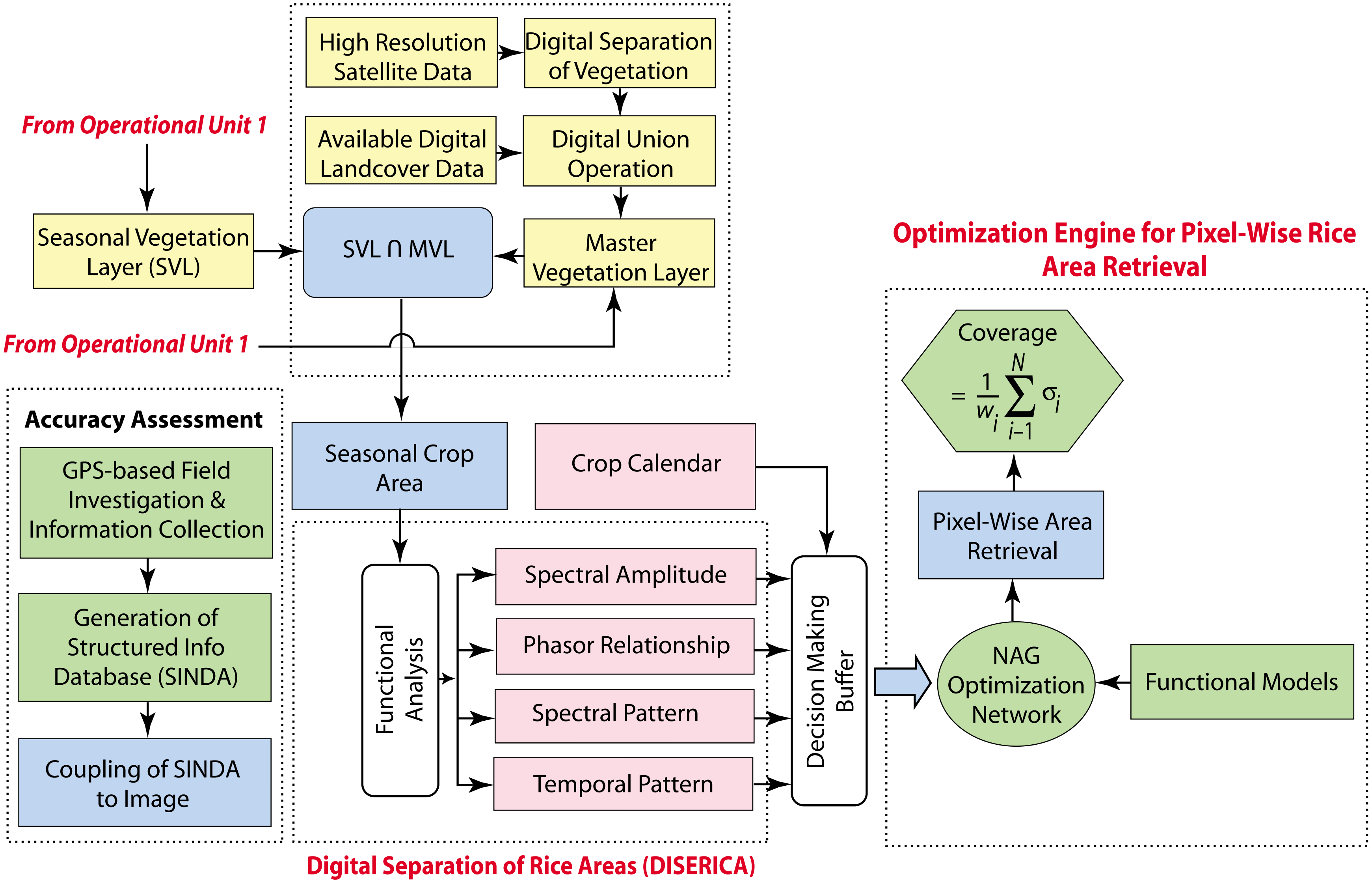

Figure 8c. Function block 3 of the crop monitoring algorithm of SPARRSO using satellite remote sensing by SPARRSO

In order to strengthen the crop monitoring activities at SPARRSO, the organization is in the process of developing broader scientific collaboration with the other relevant field level organizations in the country. Exercises on model-based numerical operations are underway to devise 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 a semi-automation scheme.

7. Possible collaborative approach

SPARRSO, the Bangladesh Bureau of Statistics (BBS) and the Department of Agriculture Extension (DAE) are 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.

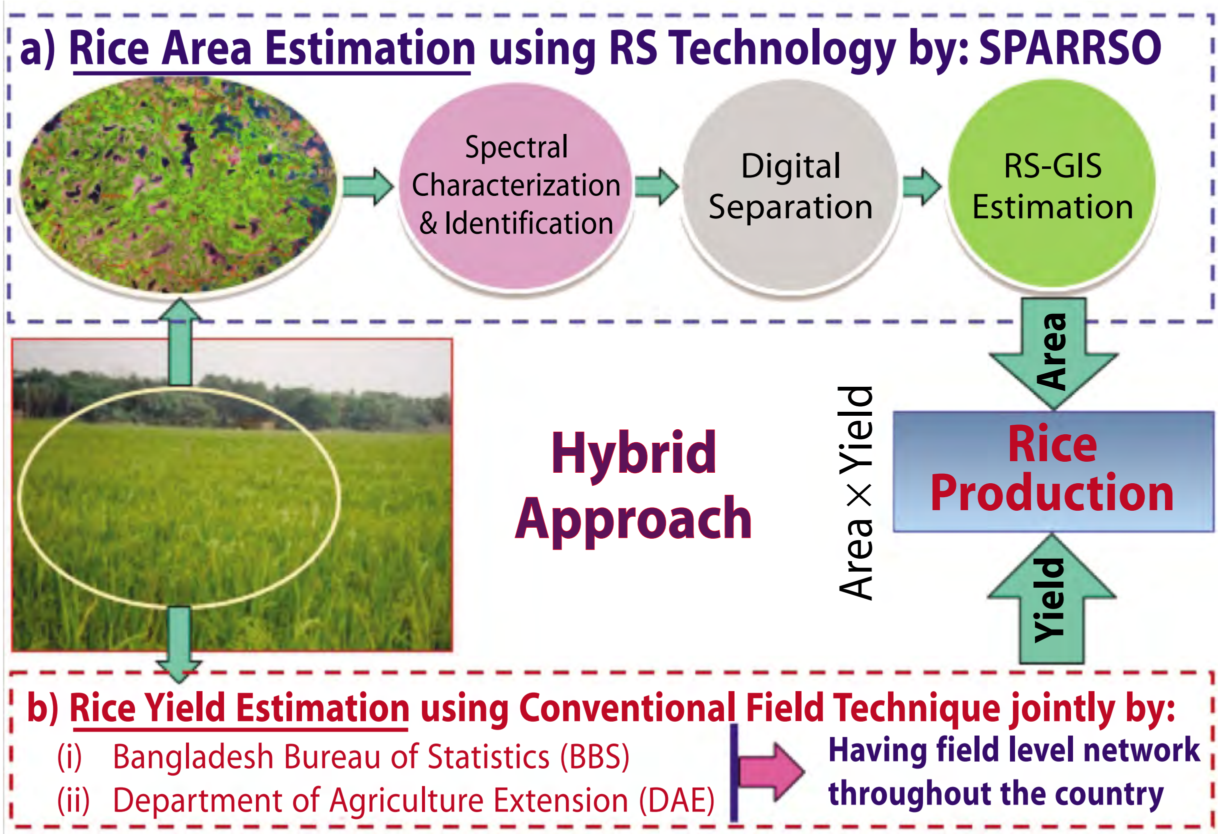

Figure 9. Strategy towards estimation of rice crop area applying remote sensing technology integrated with conventional field-based technique (Source: SPARRSO). System is under design for possible consideration.

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

8. 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 a proper methodological framework in various geo-disciplinary subject areas through development of proper algorithms 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, the 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. The 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 approaches have to be developed at the national level to better utilize the resources to achieve 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.

The Food and Agriculture Organization of the United Nations (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.

9. Acknowledgements

The author is thankful to the Food and Agriculture Organization of the United Nations (FAO) for arranging this important workshop and for providing necessary support to participate in the workshop.

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[1] ADB recognizes "Hong Kong" as Hong Kong, China

Rice objective yield survey in Japan

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Key words: Objective Yield Survey, Random Sampling, Regression Formula

ABSTRACT

Rice production is estimated by the results of an objective yield survey in Japan. The number of sample fields is around 10 000 and those are selected by random sampling. Before harvest season, yield is forecasted by the number of stocks, number of ears, number of grains and weight of 1 000 grains. When those items can be measured, the measured value is used for estimation. If not, the items are forecasted by a prediction formula. After the experimental harvest is conducted, yield is estimated by weight of sample. The current method was established as a result of several revisions, but we need to seek a more efficient method.

1. Background

Rice is a staple food in Japan. Although diversification of dietary life is making rice consumption and production decrease, it is still the main agricultural product and production of rice is 8.6 million tons and consumption of it is 7.2 million tons in 2012. The results of the rice objective yield survey are one of the most important agricultural indices and widely utilized for preparing agricultural policy by the government or for deciding on a farming plan by producers; thus, the survey results must be released accurately and quickly. The Ministry of Agriculture, Forestry and Fisheries has conducted the objective survey by using of random sampling method for more than 60 years.

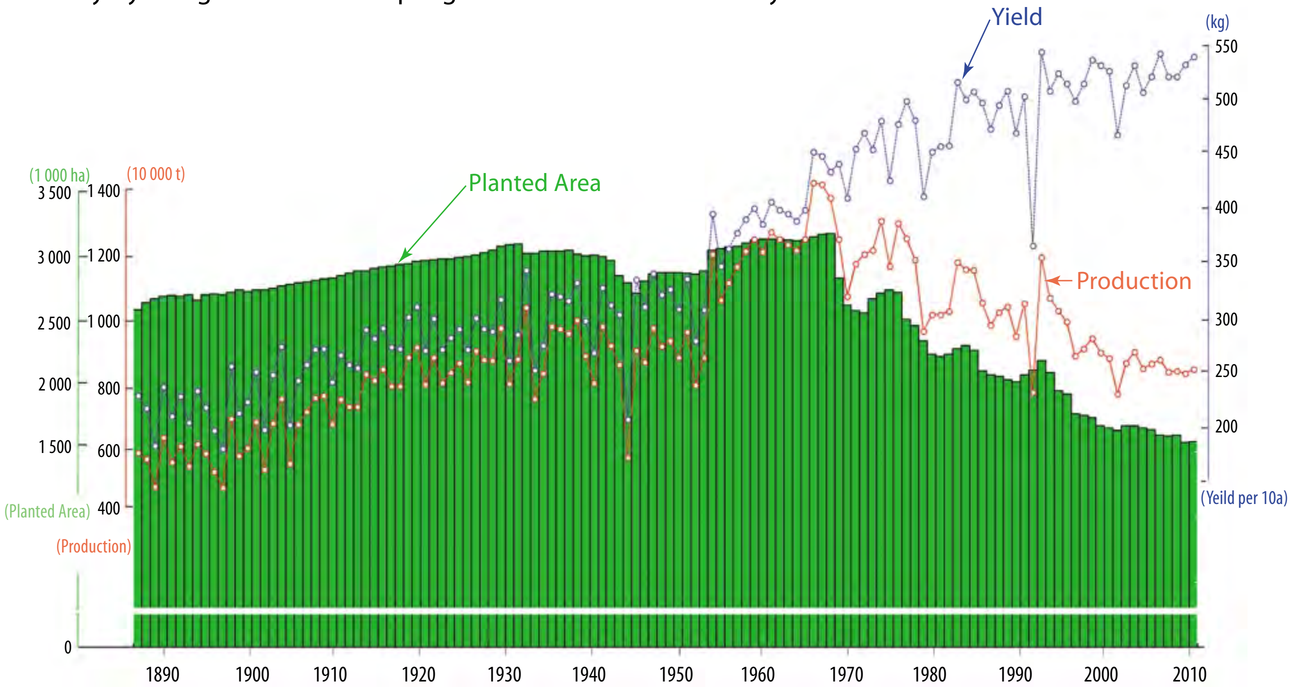

Figure 1. Change in Rice Production in Japan

2. Methodology

2.1 Purpose and system of the survey

The rice objective yield survey is conducted to prepare necessary documents for administrative measures in the fields of agriculture, forestry and fisheries, such as the estimation of supply and demand for rice and planning measures for the rice production.

The surveys are conducted 5 times a year (July, August, September, October and Harvest Season). The survey is conducted by the Statistics Department, Ministry of Agriculture, Forestry and Fisheries Japan (hereinafter referred to as "MAFF"). In the field the survey is carried out by governmental officials of Area Centres that are set in each prefecture and the result is reported to the Regional Agricultural Administration Offices and HQ of MAFF to estimate regional and national values.

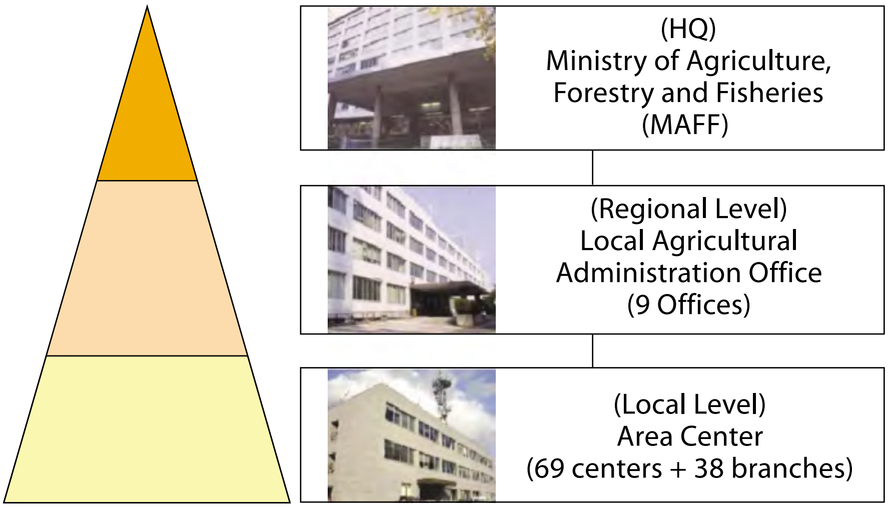

Figure 2. Organization of MAFF

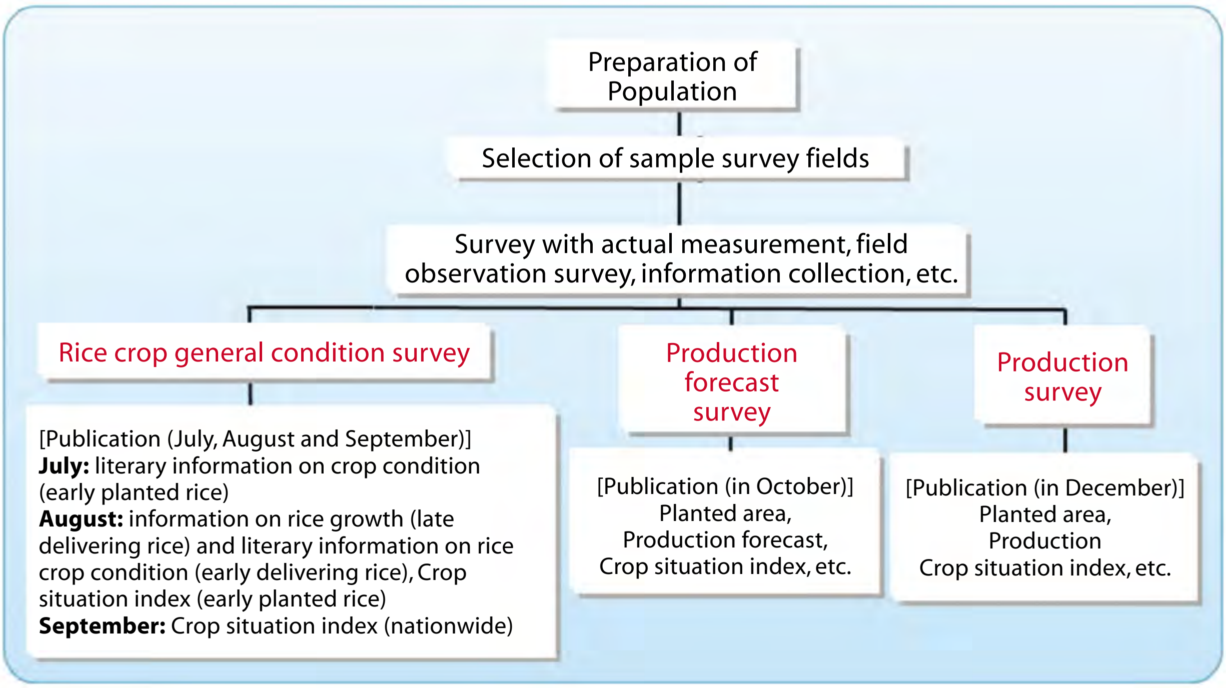

Figure 3. Survey system

2.2 Survey items

Rice is grown once a year and the cultivation period in Japan is generally from May to October. Depending on the developing stage of rice, the items of each survey are decided and the yield is forecasted based on the survey results we get at the time, before the experimental harvest survey.

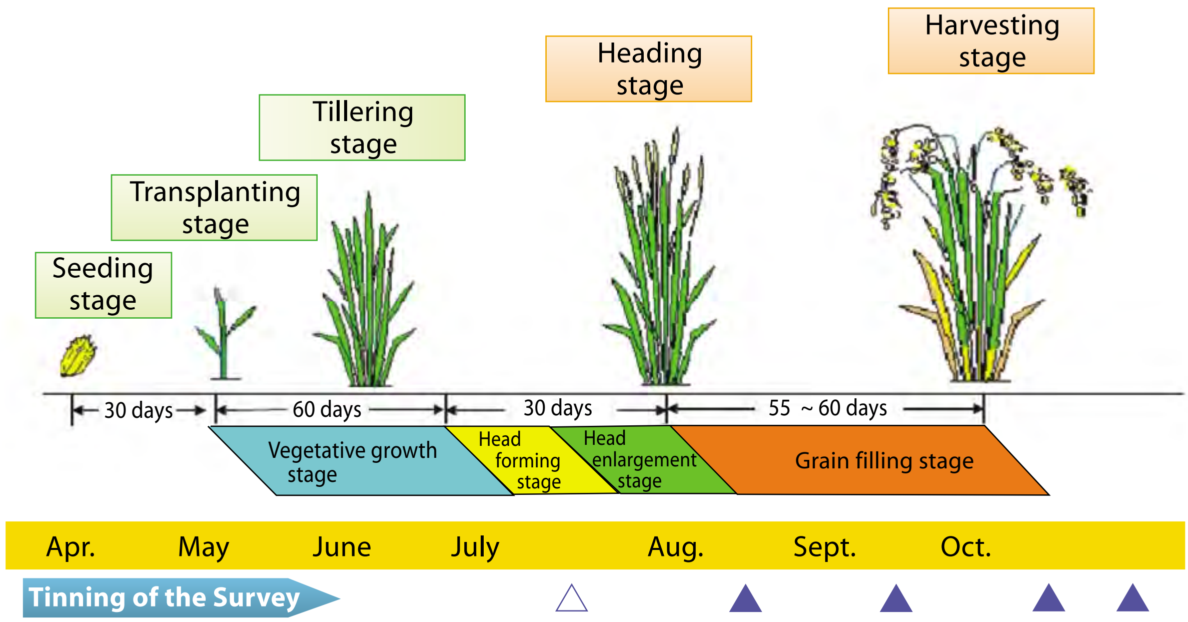

Figure 4. Growing stage of rice

Survey period \ Survey items		Seeding situation	Nursery plant condition	Planting situation	Rooting situation	Plant height	Number of stocks/number of stems	Heading/flowing situation	Number of panicles	Number of grains per a panicle	Ripening conditions	Grain growth conditions	Damage situation	Rice cultivation technology, etc.: Seeding method	Transplanting method	Changes in variety	Fertilizer application situation	Pest control situation	Harvesting method	Yield constitutional component
Rice crop general condition	July	★	★	★	★	★	★	★	★	★			★	★	★		★	★		
	August	★	★	★	★	★	★	★	★	★			★	★	★	★	★	★		
	September							★	★	★	★	★	★				★	★		
Production forecast (October)									★	★	★	★	★				★	★	★	
Production (harvest season)												★	★						★	★

Note: Only main Survey items are mentioned, due to different stages of rice development in different locations.

Figure 5. Survey items by survey period

2.3 Survey method

A. Sample allocation

a) The number of samples of each prefecture is calculated in MAFF HQ based on information gathered by the Area Centres and sent to the Regional Agricultural Administration Offices. The average of aimed precision of prefectures is approximately 1 percent. The average number of samples is around 220 fields in each prefecture and the total is around 10 000 fields.

b) Area Centres stratify the areas where they are in charge based on geography, cultivated variety, trend of cultivation, etc. Then they allocate samples to each stratum depending on the product of "Planting Area of Previous Year x Population SD of Yield per 10 are (a, 1a = 10 meter x 10 meter)".

B. Selection of sample field

a) The total area of Japan is divided into a grid of 200 m x 200 m square (a 400 m grid square for Hokkaido), which is defined as a "land unit" in this survey. Of all grids, those containing paddy fields are defined as the survey population.

b) Of the population, approximately 10 000 land units are randomly selected as sample land units.

c) In each selected sample land unit, a parcel of paddy field is randomly selected as a "sample survey field (farmland to be surveyed)" out of the paddy field planted paddy rice.

d) In each sample survey field, three points are randomly selected as points to be surveyed diagonally in farmland by the table of random numbers.

C. Measured item at sample field

a) Length of rows and stocks
We measure the length of 11 rows and 11 stocks at 3 survey points in a sample field and calculate the average of 3 points. Then we calculate the number of stocks per 1 m^2. The result is used to convert the result of the experimental harvest to yield per 10a.

b) Height of plant
We measure the height of plants of 5 stocks at 3 survey points (total 15 stocks) in a sample field to understand the growing condition.
We multiply the results of c) and d) by the number of stocks per 1 m^2 to calculate the number of stems per 1 m^2 and number of panicles per 1 m^2.

c) Number of stems
We count the number of stems of 10 stocks at 3 survey points (total 30 stocks) in a sample field to understand the growing condition.

d) Number of panicles
We count the number of all panicles and the number of sterile panicles of 10 stocks at 3 survey points (total 30 stocks) in a sample field. Then we deduct the number of sterile panicles from the number of all panicles to calculate the number of fertile panicles. The result is used for forecasting yield.

e) Number of grains
We count the number of grains of 10 stocks at 3 survey points (1st point: 3 stocks, 2nd point: 4 stocks, 3rd point: 3 stocks). At each survey point, the number of grains of the highest panicle and 2nd lowest panicle of the stock are counted and the average number of grains per panicle is calculated. Then the number of grains per 1 m^2 is calculated by multiplying the number of grains per a panicle by the number of fertile panicles per 1 m^2. The result is used for forecasting yield.

f) Experimental harvesting survey
Rice grains are cultivated in an area equal to 1 m^2 in each of the 3 survey points (an equivalent of 3 m^2 in total), and the cultivated rice grains are threshed, dried and hulled. Brown rice that is considered fit for the table is selected (i.e. brown rice ranked as third grade or higher as defined by the Agricultural Products Inspection Act and retained on a mesh sieve with openings of 1.70 mm and over) Finally yield per 10a is estimated based on the weight of brown rice considering combine loss, etc.

2.4 Method to estimate yield per 10a

Three different methods are adopted depending on the timing of estimation. At first, normal yield is estimated before planting. Normal yield is estimated on the basis of the trend of past production, taking into consideration the improvement in cultivation method and the recent trend in production, on the assumption that weather condition and crop damage are equal to those of normal years. Normal yield is used for calculating percent change from the normal year (hereinafter referred to as "Crop Situation Index"). Then, after planting, yield is forecasted by the regression formula utilizing surveyed value. Lastly, after the harvest season, the result of the experimental harvesting survey is used to estimate yield as explained in 2.3.

A. Forecast before harvesting

a) Element of yield
It is very difficult to forecast the yield per 10a with high accuracy because yield is affected by many factors. Therefore, yield is broken down according to elements and each element is surveyed or forecasted.

Number of stocks per 1 m² (19.4)	x	Number of panicles per a stock (22.2)	x	Number of grains per a panicle (69.1)	x	Weight of 1 000 paddy grains (17.5 g)	=	Yield per 10a of brown rice (522 kg)

* The values shown are only examples

Figure 6. Element of Yield

When you calculate yield by above-mentioned formula, the surveyed value is used for elements that can be measured at the time of forecast. On the other hand, elements that cannot be measured at the time are forecasted by a prediction formula based on historical meteorological data and surveyed data.

b) Prediction formula
A multiple regression equation is adopted as a prediction formula. Historical meteorological data and surveyed value are used for variables of the equation. Among elements of yield, a weight of 1 000 grains cannot be measured before conducting the experimental harvest survey so it is vital to forecast the weight of 1 000 grains as accurately as possible. Therefore, we use surveyed value as soon as we get it and meteorological data which is selected by knowledge of crop science for variables to forecast the weight of 1 000 grains. One example is shown below (Variables are different among prefectures.).

$$Y = 5.470 + 0.205(X1) - 0.023(X2) - 0.003(X3)$$

$R^2 = 0.958$

Y: Weight of 1 000 grains
X1: Rate of Insemination
X2: Total number of unripened rice per 1 m²
X3: Accumulated 20 days of low temperature after heading of panicle

Figure 7. Example of Multiple Regression Formula

c) Change in yield by survey period

When we see a change in yield per 10a by the survey period of the last 10 years, it is little changed from October to the final data. From September to the final data, it decreased an average of 5 kg in the year when serious damage was caused by typhoon. When we compare the Crop Situation Index, it is little changed from September to final data.

Unit: kg

Year	Sept.	Oct.	Final Data	Reason of Change
2004	528	514	514	Injury of Ripening by typhoon and long period rainfall
2005	536	532	532	Injury of Ripening by high temperature and insects
2006	515	508	507	Salty wind damage
2007	523	522	522	
2008	542	543	543	
2009	521	522	522	
2010	526	522	522	Injury of Ripening by high temperature
2011	535	533	533	
2012	539	540	540	
2013	543	539	539	Typhoon, insects and disease

Figure 8. Changes in Yield per 10a by Survey Period

Year	Sept.	Oct.	Final Data	Reason of Change
2004	101	98	98	Injury of Ripening by typhoon and long period rainfall
2005	102	101	101	Injury of Ripening by high temperature and insects
2006	97	96	96	Salty wind damage
2007	99	99	99	
2008	102	102	102	
2009	98	98	98	
2010	98	98	98	
2011	101	101	101	
2012	102	102	102	
2013	102	102	102	

Figure 9. Changes in Crop Situation Index by Survey Period

B. Calculating normal yield per 10a

When we estimate normal yield, we consider that elements of yield variation consist of moderate annual variation caused by changes in the production situation such as composition of variety and meteorological variation. Then moderate annual variation is shown by spline function and meteorological variation is shown by multiple regression equation.

First, historical data of yield per 10a since 1979 is prepared and the element of meteorological variation that affects yield is removed from the historical yield data to estimate the correction value of yield. Then trend value is estimated by spline function using the correction value. Finally we estimate normal yield based on the correction value taking into consideration the latest production situation.

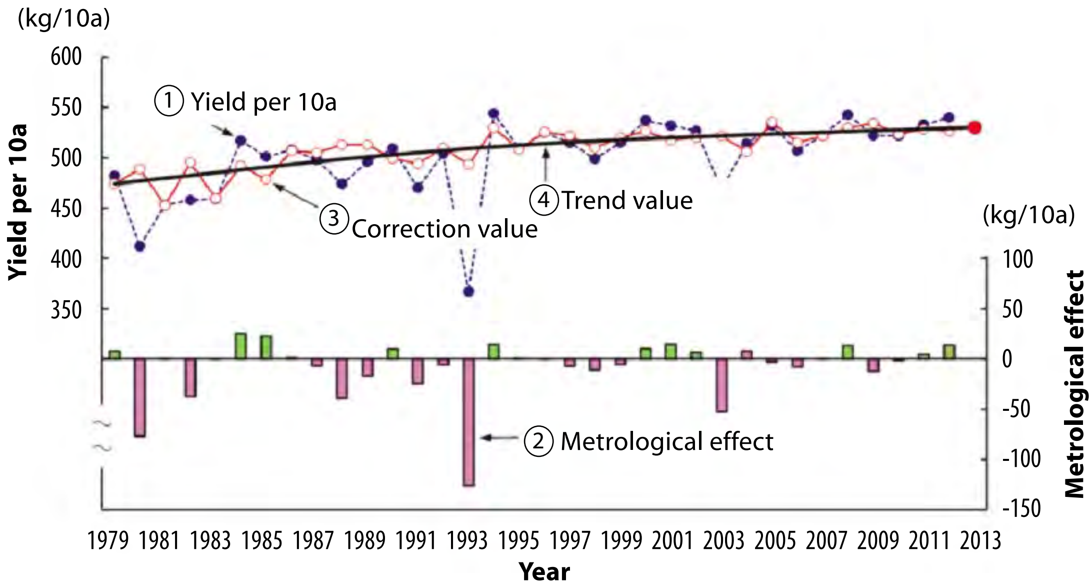

Figure 10. Estimation of normal yield

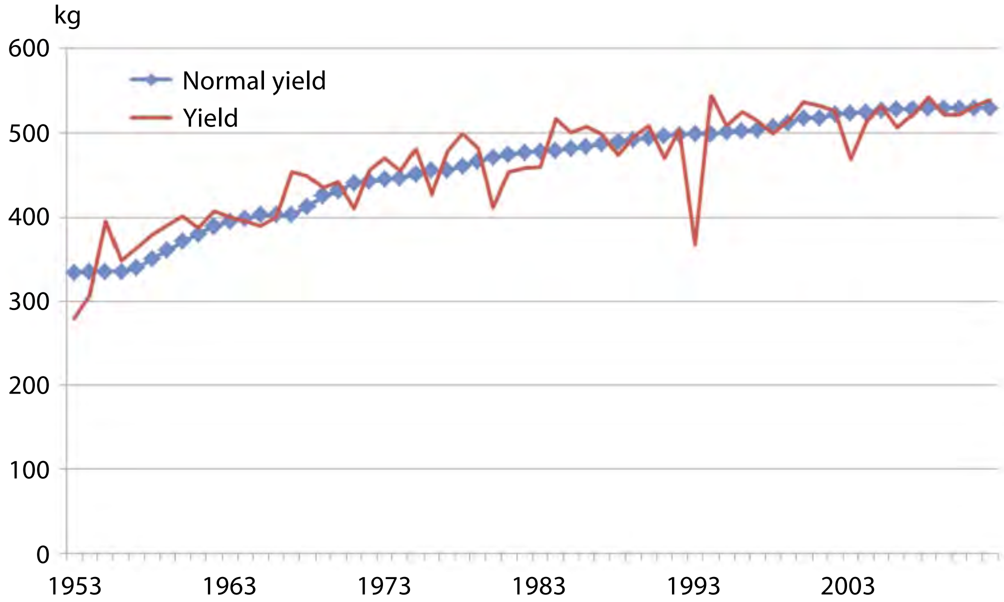

Figure 11. Changes in yield and normal yield

2.5 Crop situation index

The Crop Situation Index measures the rice production situation of the year and is defined as a ratio of "forecasted yield per 10a" to "normal yield per 10a". This index is published August, September, October and December and is very popular in Japan because it shows the rice production situation straight.

$$\boxed{\text{Crop Situation Index}} = \frac{\boxed{\text{Yield per 10a}}}{\boxed{\text{Normal Yield per 10a}}} \times \boxed{100}$$

Figure 12. Crop situation index

3. Conclusions

The result of the survey estimated by the above-mentioned method has a quite high accuracy and the Standard Error Ratio is 0.13 percent in the national total in 2012. The result is utilized for several agricultural policies such as forecasting supply and demand of rice.

Although our current survey system is well established, we have made many efforts to reach the current system over more than 60 years conducting surveys every year and revising the methods many times to make the survey more accurate and efficient, taking into account user needs, progress of the cultivation method, budget and the number of staff of the organization.

For example, the number of sample fields was reduced from approximately 34 000 in 1965 to approximately 10 000 in 2012 and the area of survey points of a sample field was also reduced from 9.9 m^2 (3.3 m^2 x 3 points) to 3 m^2 (1 m^2 x 3 points). Regarding the method of forecasting yield, direct forecast was tried before but currently we have adopted a method to resolve yield into its composition elements and survey or forecast each element as explained earlier. Furthermore, normal yield was originally the average of past years and the estimation method was revised to use the regression formula but now it is estimated by using the spline formula to reflect recent trends more adequately.

Of course we still have challenges to overcome. As just described, the current system has great accuracy but we need to streamline the method more while keeping the accuracy of the survey. A lot of officials are necessary to conduct the current survey system, especially for the field survey, but unfortunately the number of staff is expected to be decreasing in the future. Although we do not have a specific idea now, we might consider reduction of samples, change of survey method, introduction of new technology etc. We hope to find some hints in presentations of the expert meeting for our future consideration.

Sampling frame of square segment by points for rice area estimation

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Key words: Area frame sampling, Rice statistics

ABSTRACT

Rice is staple food for most Indonesian people. This commodity plays an important role in the economy of Indonesia. Because of this, the government of Indonesia should be careful in drawing up certain policies, especially relating to the context of rice crop development planning. Accurate and timely data are needed to support the policy of rice crop development planning. Statistical services on agriculture are based on different approaches, as a result of both historical reasons and available techniques, to provide reliable figures. Most often, the applied systems are based on village statistics, census, sampling survey based on list frame or area frame, and administrative by-products. Area Frame Sampling is one of the methodologies used to estimate rice crop area and furthermore rice crop production. In this method, crop area estimates are extrapolated from samples to population, where sample data is directly obtained from field observations. Data communication from field level to central level by the SMS gateway is involved to support timely generation of reliable information on the crop area. In the present paper, we mainly try to review the approach of area frame sampling for rice estimate that has been developed in Indonesia for several years. The discussion focuses on area frame construction, field survey, data communication and some results.

1. Background

Agricultural sector is renewable resources which has an important role in the national economics structure, especially in developing countries like Indonesia. At present, food commodity especially rice still has an important role regarding to daily life of the people and also as a part of economic activity which can accommodate a lot of labors to employ on it. Rice is a staple food for Indonesian people and frequently called as a political commodity due to its vital role, it is to say that unstable of the national rice stock would be followed by unstable of the national politics condition. Improvement of the rice production has been conducted by government through various efforts in order to increase not only harvested area but yield as well. Becouse of the rapid growing cycle of rice dynamic, the accurate and timeline information are needed as an input for decision making to define appropriate management from farm level up to national level.

At present, the data of rice area is reported manually from the sub-district level by using the SP-IA list and assimilated up to the national level. The results tend to bias due to the subjective factor and many iterations of combining statistics. For that reason, the methodology development is needed in order to get more accurate and objective figures of rice statistics. One of the methods used in deriving agricultural statistics is the sampling technique in which a partial observation of agriculture is conducted for extrapolating the whole population.

Area frame sampling of a square segment by points (AFS) is a statistical procedure to measure the quantity of rice area in a geographic region of interest by observing sample points inside square segments as a small part of the population. The procedure has adopted the SARI Project in technical cooperation between EU, BPPT, MoA, and CBS from 1998 to 2000 (BPPT-EU, 2001). The improvement of the survey method and data communication from farm level to central level is still being continued. The present paper discusses the principle of area frame sampling and its implementation.

2. Methods

The technique of area frame by points was the operational application in the French TER-UTI survey (Porchier 1990) and European LUCAS (EC 2003). The construction of an area frame of square segment by points is essentially the same as a normal area frame, except that only a set sample of points inside a segment is visited instead of the whole segment and no fields must be delineated. Based on the observation of sample points, area estimates are computed and used as a valid generalization without studying the entire area under investigation. The discussion in this paper is focused on area frame construction, field survey, data communication and some results of the pilot study in Indramayu District, West Java.

2.1 Area frame construction

In the area frame construction not only Indramayu District but also other districts of West Java Province were built in the coincidence works. Then the administrative boundary was used to cut off the study area of Indramayu District. A land use map was used to delimit and stratify the study area.

Stratification aims to divide a population (Ω) of size N into H non-overlaping sub-populations (Ω_h-strata) of size N_h in order to get more efficiency in both level of accuracy and cost (Taylor *et al.* 1997). Considering the classes of present land use on the maps and with the intention to obtain only two strata for each District – a bigger number of strata would in fact give us too big a sample dimension. The study area is divided into three catagories (Mubekti and Hendrarto 2010):

- Strata-0 or "non-rice" is the polygons with no rice field content, such as forest, settlement, water body, etc.
- Strata-1 or "rice" is the polygon which has a high expected percentage of rice field content, i.e. irrigated rice field and rainfed rice field.
- Strata-2 or "possibly rice" is the polygon which has a low expected percentage of rice content, i.e. upland arable.

Figure 1 shows the spatial stratification in the study area.

The results of the stratification show that the total area of Indramayu district is 207 675 hectares, consisting of 142 950 hectares strata-1, 2 800 hectares strata-2, and 61 925 hectares strata-0. The area of the sampling frame is the sum of strata-1 and strata-2, while strata-0 is not included from sampling frame.

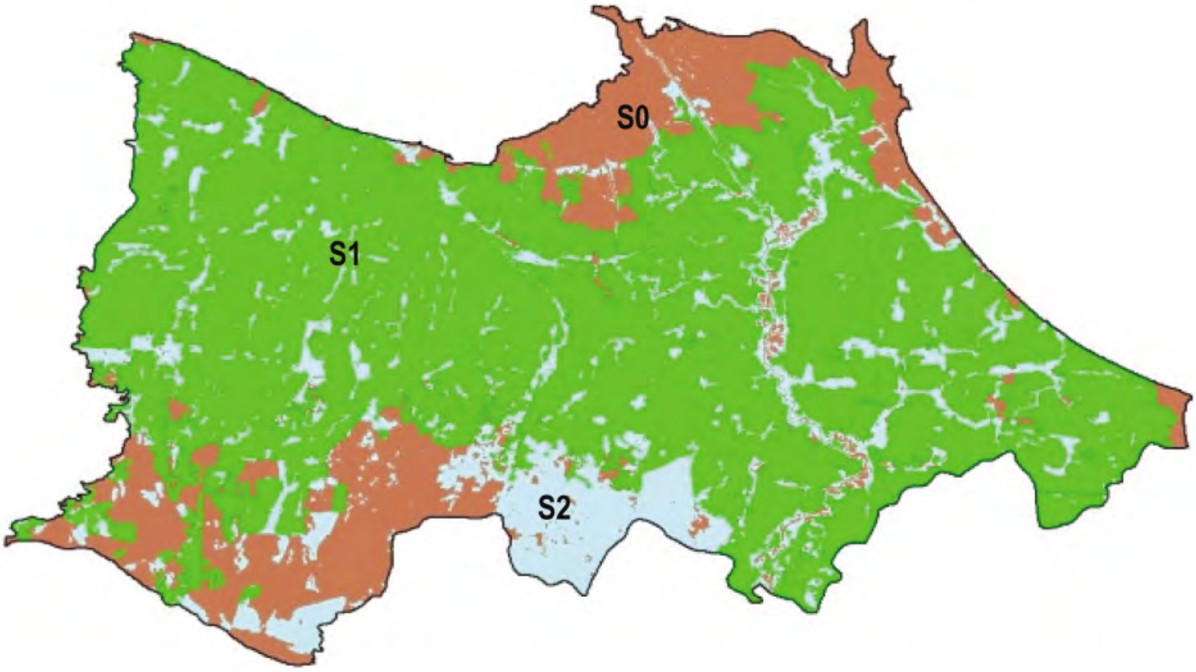

Figure 1. Stratification map of study area

Since the area frame refers to a square segment, then a fishnet of an elementary unit sized 500 m x 500 m is set by converting the stratification map to make easier sampling (Figure 2). The results of the set fishnet show that the total of the area frame is 5 830 cells consisting of 5 718 cells strata-1 and 112 cells strata-2.

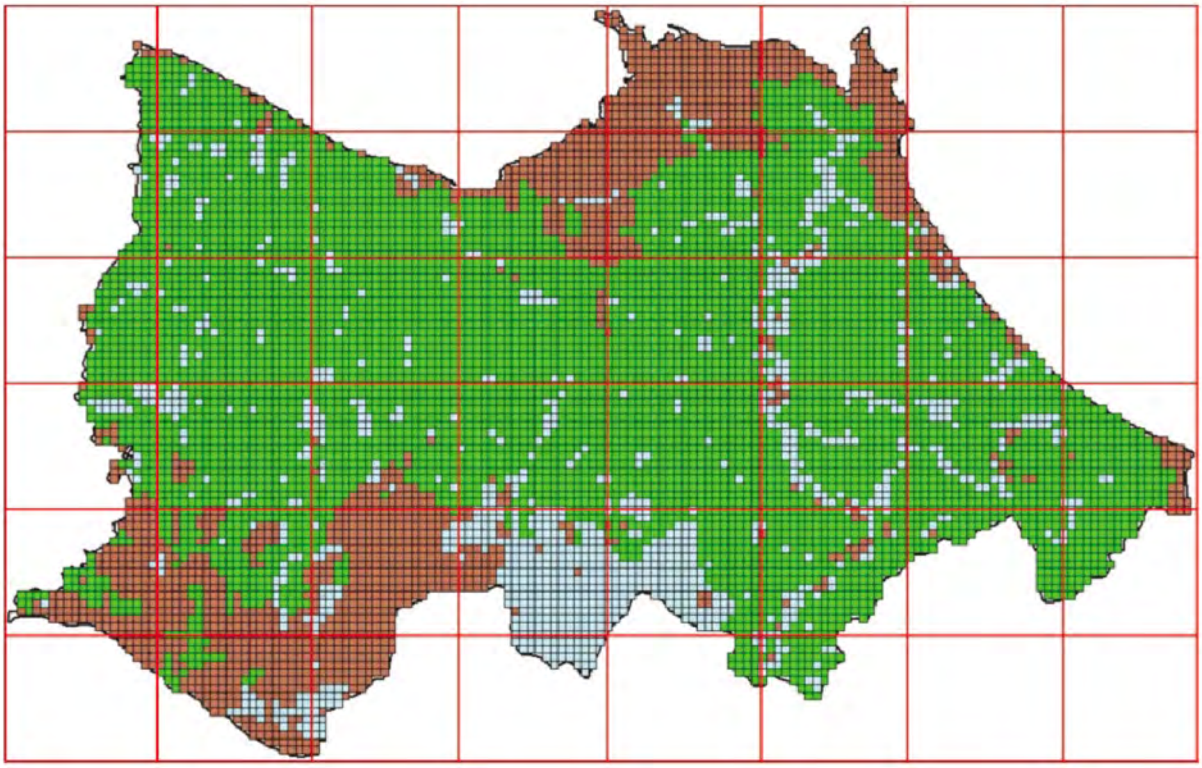

Figure 2. Grid cell map of study area

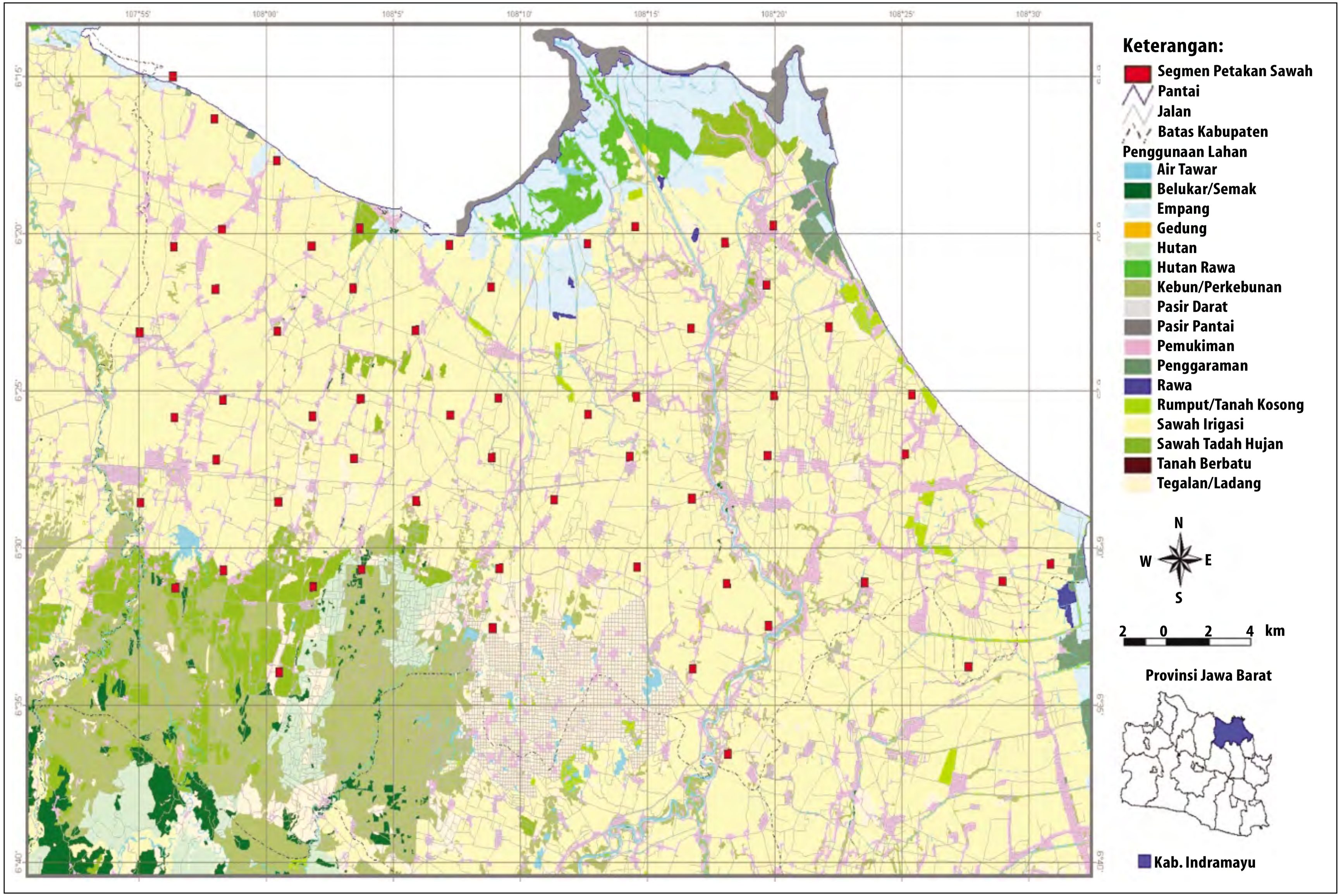

Figure 3. Distribution map of sample segment

In the statistical inference estimation process the sample dimension is always a crucial point. The statistician has to find the best solution to fit the cost of the survey with acceptable data estimation accuracy. Also to be considered are the difficulties arising from the operative point of view since it is certainly a huge task to make the process starting from planning, training, field survey, up to data analysis. Due to these operative problems the sample dimension was set considering the minimum acceptable dimension. In this study the dimension of sample segments is approximately 1 percent of the area frame. Because of the very small sample segment in strata-2, it was decided to use only one stratum where strata-1 and strata-2 are combined together.

After defining the sample dimension the methodology was analyzed to randomly extract the elementary units. In spatial statistics it is very important to manage samples geographically distributed in the whole study area. The selected method is known as "Systematic Aligned Sampling with a distance threshold" (Gallego 1995). The GIS Arc-View software was employed to extract sample segments.

This method involves the division of area frames into blocks of segments and the selection of a fixed number of segments in each block repeating the same "replicate". The replicate is a fixed pattern or location of selected segments in one block. The same selected segment positions in each block are used.

The selected block was 10 x 10 km wide, containing 400 segments of 500 m x 500 m and in each block 10 segments were drawn. Only the segments that exceed a distance threshold between each other were kept and sequentially numerated. The general rule is to use the first 4 positions to obtain the desired sample dimension. The extraction method refers to "Systematic Random Sampling" using a distance threshold. If it needs modification, additional location numbers can be added. Figure 3, illustrates the distribution of extracted sample segments on a land use map. The total number of extracted sample (n) is 52 segments spread over 29 sub-districts out of the total 31 sub-districts available in Indramayu District. Each extracted sample segment is assigned a code number and geographical co-ordinate at the bottom-left corner.

The next step is to locate sample points; 25 sample points will be allocated inside each segment. The implementation is to make a grid cell of 100 m x 100 m size on the extracted sample segments. The center of each grid cell is to be the sample point for field observation. The surveyor will only write down the land use in each of the 25 points instead of drawing and further digitizing all the fields in the segment. For the whole of Indramayu district there are 52 (segments) x 25 (points) = 1 300 sample points.

2.2 Field survey

In the study, the boundary of the segments is not a physical feature but is based on geographical boundary, so it needs supporting material to identify the location of sample segments and observation points when the field survey is done. A land use map (scale 1:25 000) and aerial photograph or high resolution of satellite image (scale 1:2 500) are used as supporting material where all sample segments and observation points are plotted on it. The results can be used as a field map for survey guidance. Figure 4. illustrates how to plot sample segments on a land use map and observation points on aerial photographs regarding their geographical coordinates.

By using the above guidance the surveyors can look for the locations of sample segments and observation points based on the features available on the maps, such as road, settlement, irrigation canal, etc. The aim of the survey is to collect rice data directly from the field by observing rice growing stages in each point inside the sample segment. A simple training of surveyors is needed in order to know: 1) how to find point location on the field; 2) how to fill the form; and 3) how to send the field data.

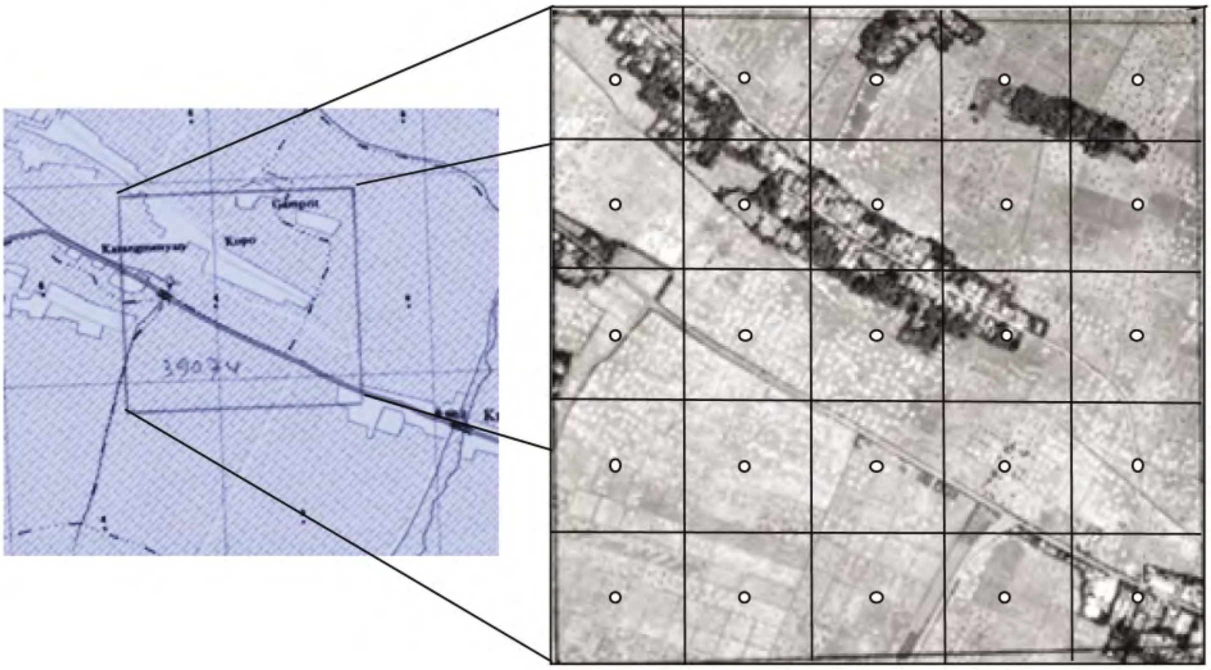

Figure 4. Illustration of sampel plot on land use map

The field survey activity was conducted by the available agricultural field officers at each observation point and they wrote down the stage of rice crop on the form (see Figure 5), as follows:

- Vegetative-1 (V-1): the approximate stage of rice is 1-35 days after transplanting;
- Vegetative-2 (V-2): the approximate stage of rice is 35-55 days after transplanting;
- Generative (G): the approximate stage of rice is 55 days up to harvest;
- Harvested (P): the stage of rice from harvested up to land preparation;
- Land Preparation (PL): the rice field being prepared;
- Others (LL): land not used for rice crop cultivation;
- B: if rice field is not cultivated (bare); and
- H: harvested rice in between two surveys.

Knowing the above rice growing stages is important because the calculation of rice area and the prediction of rice harvested area will refer to those stages.

2.3 Data communication and analysis

In order to accelerate the delivery of data from the field to the central (Jakarta) server, a communication system have been developed by using a short message service (SMS). The structure of SMS communication system is shown in Figure 6. Surveyors send field data via SMS corresponding to the results of recording the amount of each stage per segment as soon the observation of all points is finished. All field data will be stored in the SMS server for advanced processing. The address of the system can be visited at: http:neonet.bppt.go.id/padi/.

FORMULIR LAPORAN
SURVAI FASE PERTUMBUHAN TANAMAN PADI
KABUPATEN KARAWANG

Nomor Segmen	321774102

Survai yang Lalu	
Tanggal Survai	
Kode Survai (Bl Thn)	

Utara

	A	B	C	D	E
1					
2					
3					
4					
5					

Selatan

Survai Saat Ini	
Tanggal Survai	27 Sept. 2011
Kode Survai (Bl Thn)	911

Utara

	A	B	C	D	E
1	P	PL	PL	V1	V1
2	LL	PL	V1	V1	V2
3	LL	PL	V1	V1	V2
4	LL	PL	V1	V1	V2
5	PL	PL	V1	V1	G

Selatan

Rekapitulasi Fase Pertumbuhan

PL =	07
V1 =	10
V2 =	03
G =	01
P =	01
LL =	03
B =	00
H =	00

Format SMS

AFS	Kode Survai	No. Segment	PL	V1	V2	G	P	LL	B	H
AFS	0911	321462106	07	10	03	01	01	03	00	00

Contoh:
Ketik: AFS 0911 321462106 07 10 03 01 01 03 00 00
Kirim ke Nomor: 0813-1975-8855

PL:	Persiapan Lahan (Olah Tanah)
V1:	Fase Vegetasi Awal
V2:	Fase Vegatasi Akhir
G:	Fase Generatif

P:	Padi sedang/sudah dipanen
LL:	Lain-lain tutupan lahan
B:	Bera (Jika dalam 2 Survai berurutan tidak ada aktifitas penanaman)
H:	Harvested, Jika ada panen antara waktu 2 Survai (yang lalu dan saat ini)

Karawang 27 September 2011
Surveyor

(SUHENDL)

Figure 5. Illustration of field survey form of rice growing stages

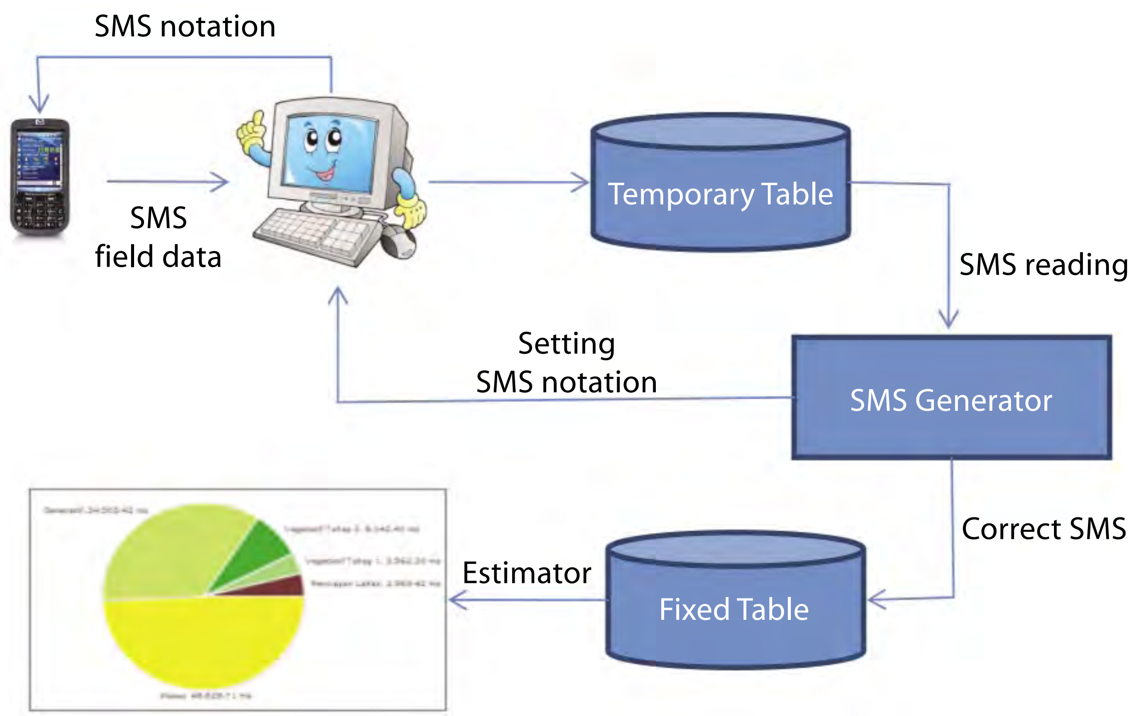

Figure 6. Structure of SMS communication system for AFS

The extrapolation formula of sample to the population is also inserted in the SMS server system. Therefore, the field data submitted by the surveyors would be immediatly calculated by the system to estimate rice crop production. The mathematical formula for rice production estimate is given below:

- Rice area (A)
  D_j = Total area of strata j
  n_j = sample dimension in strata j
  m = number of strata
  p_{ij} = proporsion of rice area in segment i strata j
  A_j = Total area of rice in strata j j
  D, Total area of the frame in the study area

The average proportion of rice area in strata j and its variance are calculated by the formula below:

$$\overline{p}_j = \frac{1}{n_j}\sum_{i=1}^{n_j} p_{ij} \qquad \delta^2_{\overline{p}_j} = \frac{1}{n_j(n_j-1)}\sum_{i=1}^{n_j}(p_{ij}-\overline{p}_j)^2$$

Total rice area in strata j and its variance are calculated by the formula below:

$$A_j = D_j\overline{p}_j \qquad Var(A_j) = D_j^2\delta^2_{\overline{p}_j}$$

The estimation of the total rice area in the study area is done by adding the rice areas in all strata. The mathematical formula of rice area and its variance is as follows:

$$A = \sum_{j=1}^{m} A_j$$

The standard error is calcualted from the root of the variance, then the coefficient variation is stated as the percentage between standard error and estimated area of rice.

3. Results

Each time the field survey is conducted and field data are sent to the SMS server by the surveyors, the results of the rice estimates can immediately be seen on the website (http:neonet.bppt.go.id/padi/).

The attached table is a sample of field survey data conducted 3-10 September 2012 for Indramayu District of West Java Province. This district has area of 207 675 hectares devided into 3 strata, namely 142 950 hectares of S-1, 2 800 hectares of S-2, and 61 925 hectares of S-0. S-0 is non-agricultural land so it is not sampled. Because of the small area of S-2 it is merged with S-1 into one strata; then the area of the sample frame is 145 750 hectares.

The next process is to estimate the rice area based on the proportion of each growing stage as shown in Table 1. The proportion of each growing stage is calculated from the ratio between the total observed points and total sample point. The area of each growing stage is calculated by multiplying proportion and area of sample frame.

Table 1. Illustration of rice area estimation in Indramayu District

Rice growing stage	Total observed points	Proportion (%)	Area (Ha)
Land Preparation (PL)	17	1.3	1.895
Vegetatif-1 (V1)	17	1.3	1.895
Vegetatif-2 (V2)	74	5.7	8.308
Generative (G)	73	5.6	8.162
Harvest (P)	412	31.7	46.203
Other land cover (LL)	340	26.2	38.187
Uncultivated rice field (B)	367	28.2	41.102
Harvest in between 2-survey (H)	38	2.9	2.226
Harvest next 2-month			16.470
Harvest next 4-month			20.260

Note: Total sample in study area is 1 300 points

Since the rice growing cycle is 105 days, then we can predict the rice harvest area for the next two-months and four-months referring to the area of growing stages. For example, the prediction of rice harvest area for next two months is the sum of the area of vegetative-2 and generative stages, that is 16 470 hectares. Furthermore, the area of the rice harvest area for next four months is the sum of the area of land preparation, vegetative-1, vegetative-2, and generative stages: that is 20 260 hectares.

The extraction of sample segments is done by probability sampling where the selected sample segments are the representation of the rice field population; then the above results will be an unbiased estimate.

4. Conclusions

1. There are various types of approaches to collecting agricultural statistics; one of them is area frame sampling.
2. Area frame of square segment by points is a simple approach to implement for rice statistics.
3. Area frame sampling is a scientifically sound approach based on statistical analysis and unbiased by subjectivity.
4. Using the SMS system for data communication allows us to get near real time results.
5. Area frame sampling is based on low technology and does not need high investment costs.
6. Iimplementation costs are very low once it has become a routine activity.
7. With slight adaptations it can be applied to other crops.

5. Success achieved and issues for further research

1. Related institutions, i.e. MoA, CBS and UKP4 (Presidential Office for Develoment Monitoring), give a high attention to support the method for National level implementation.
2. The pilot project of the method is mainly dedicated to the district level, so there is still need for adaptation to up-scale or down-scale levels in respect to sample size and segment size.
3. The method will be improved for not only rice statistics but also for secondary food crops statistics.
4. The integration method between rice area estimate and yield estimate needs further research, where the existing sampling frame of yield estimation based on household frame will be on area frame instead.

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Attached Table

Field data of AFS survey based on selected sample segment

No.	Sub-District	Segment	Growing stages							
			PL	V1	V2	G	P	LL	B	H
1	Sindang	321470803	0	0	0	0	20	5	0	0
2	Kandanghaur	321470603	0	0	0	0	21	4	0	0
3	Kandanghaur	321466406	0	0	0	0	22	3	0	22
4	Kandanghaur	321470504	0	0	23	0	0	2	0	0
5	Losarang	321466503	0	0	0	0	23	2	0	11
6	Losarang	321470601	0	0	0	0	0	25	0	0
7	Bangodua	321462403	0	0	0	0	20	5	0	0
8	Cantigi	321470704	0	0	0	0	0	21	4	0
9	Bangodua	321462304	0	10	0	0	6	4	5	0
10	Sliyeg	321466601	0	0	0	0	24	1	0	0
11	Sliyeg	321466604	0	0	0	0	5	20	0	0
12	Kertasemaya	321462503	0	0	0	0	13	12	0	5
13	Krangkeng	321462603	0	0	0	0	0	2	23	0
14	Krangkeng	321458406	0	0	0	0	0	25	0	0
15	Anjatan	321470401	0	0	0	24	0	1	0	0
16	Juntinyuat	321466704	0	0	0	0	20	0	5	0
17	Juntinyuat	321466701	0	0	0	0	18	7	0	0
18	Cikedung	321462201	0	0	0	0	0	5	20	0
19	Cikedung	321462204	0	0	0	0	0	8	17	0
20	Anjatan	321466206	0	0	0	20	0	5	0	0
21	Anjatan	321470403	0	0	18	0	0	7	0	0
22	Haurgeulis	321462006	0	0	0	0	0	0	25	0
23	Haurgeulis	321466204	0	0	0	0	0	2	23	0
24	Haurgeulis	321466203	0	0	0	0	0	8	17	0
25	Haurgeulis	321466201	0	0	0	0	0	5	20	0
26	Gabuswetan	321466303	0	0	0	0	23	2	0	0
27	Gabuswetan	321466304	0	0	0	0	16	9	0	0
28	Gantar	321462003	0	0	0	0	0	6	19	0
29	Terisi	321466401	0	0	0	0	23	2	0	0
30	Gantar	321462106	0	0	0	0	0	5	20	0
31	Gantar	321462004	0	0	0	0	0	14	11	0
32	Gantar	321457906	0	0	0	0	0	8	17	0
33	Balongan	321466706	0	0	0	0	0	25	0	0
34	Widasari	321462406	0	0	0	0	25	0	0	0
35	Kroya	321466301	0	0	0	0	0	0	25	0
36	Kroya	321462206	0	0	0	0	0	3	22	0
37	Kroya	321462103	0	0	0	0	0	5	20	0
38	Kroya	321462104	0	0	0	0	0	0	25	0
39	Cikedung	321462306	0	0	0	0	0	5	20	0
40	Lohbener	321466606	0	0	0	0	23	2	0	0
41	Lelea	321466501	0	0	0	0	12	1	12	0
42	Lelea	321466504	0	0	0	0	6	2	17	0
43	Losarang	321466404	0	0	0	0	25	0	0	0
44	Losarang	321466403	0	0	0	0	0	25	0	0

No.	Sub-District	Segment	Growing stages							
			PL	V1	V2	G	P	LL	B	H
45	Tukdana	321458206	0	0	0	0	12	13	0	0
46	Tukdana	321462401	0	0	0	0	25	0	0	0
47	Patrol	321470506	0	0	0	0	9	16	0	0
48	Patrol	321470404	0	2	22	0	0	1	0	0
49	Sukra	321474601	17	5	0	0	0	3	0	0
50	Sukagumiwang	321458203	0	0	0	0	21	4	0	0
51	Bongas	321470503	0	0	6	15	0	4	0	0
52	Bongas	321470501	0	0	5	14	0	6	0	0
TOTAL			**17**	**17**	**74**	**73**	**412**	**340**	**367**	**38**

Experience of crop cutting experiments in Thailand

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ABSTRACT

Yield-Per-Rai Survey by Method of Crop-Cutting is another method that helps the harvest process and presents credible data which instills confidence for general data users since it applies scientific procedures that rely on counting, measuring, and weighing techniques to the actual yield within the cultivation area by simulation practices by establishing conditions and practice methods aligned for the purpose of data inference, which is an accurate snapshot of the population.

This paper mentions the operational details comprised of 3 activities, i.e. Crop-Cutting Survey, Gleaning Survey, and Dyke Survey. The net yield is estimated as:

Yield (at field moisture content) = (crop cutting survey – gleaning survey) Dyke ratio*

1. Survey methods

1.1 Random sampling plan

The *Rice Survey Manual* for the harvest year 2012/13 previously mentions List Frame methods which simultaneously combine data yield survey with methods of crop-cutting and post-harvest survey methods under the same random sampling plan by reasoning of statistical theory. However, yield-per-rai (Note: 1 ha = 6.25 rai) data survey counts and records the names of new farm households that are capable of harvesting within the timeframe, followed by random sampling of 3 households. Moreover, some of the sample households within the yield-per-rai survey by means of Crop-Cutting will also be sample units in the List Frame survey.

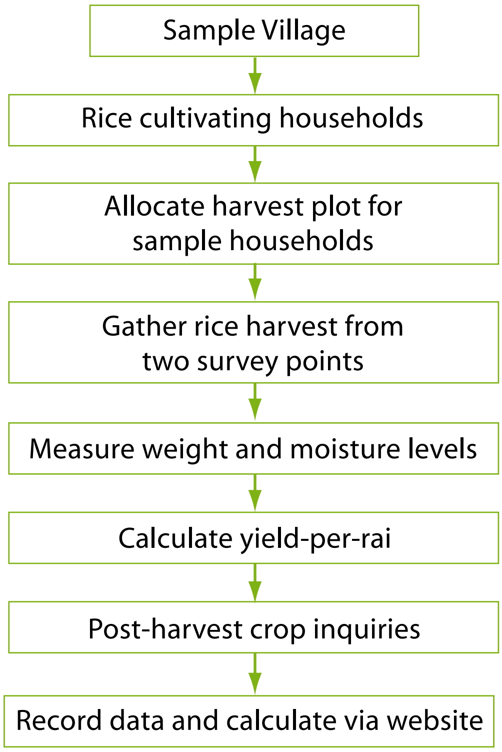
1.2 Operational procedures

The Office of Agricultural Economics receives the list of sample villages from the yield-per-rai survey during the 2012/13 rice harvest, whereby some provinces may categorize sample villages independently inside and outside the irrigation zone. This list of villages is a separate list from that applied under the List Frame Sampling. Therefore, officers are capable of immediately implementing operations within the target areas for the harvest. Furthermore, when problems are encountered that necessitate switching to the reserve samples, it is possible under the established guidelines.

1.3 Amount of random samples

The yield-per-rai survey of the sample villages comprises three households, wherein each household is required to allocate two harvest plots from the sample field (random sampling of the plot and field is described in the manual and Crop-Cutting yield survey records).

1.4 Summary of operational methods



Each province has a list of sample villages which will be surveyed on a yield-per-rai basis by means of Crop-Cutting; these villages are samples taken from previous surveys.

Operatives must count and record the names of rice cultivating households, which will gather harvest within the set time period, and collect at random three samples of households to set the Crop-Cutting schedule.

Two Survey points are allocated per each sample household.

The rice harvest is gathered from two survey points of one square meter per point (1 m x 1 m) and placed in mesh bags prepared beforehand. The crops from each survey point are separated in each bag.

2. Crop cutting operations

2.1 Operational work procedures

The Crop-Cutting operations rendered to the rice plots of sample farm households are procedures implemented for the same group of samples under the List Frame Survey. This includes counting, recording, and random sampling of the households that gather harvest within the set time period by officers assigned to the Crop-Cutting operations, who meet with the sample households and perform random sampling of two survey points and gather the crops.

In case of Force Majeure which would prevent Crop-Cutting procedures at the rice cultivation plots of sample households, officers are able to change the sample households in sequence, but must clearly specify credible cause to justify such changes rendered.

2.1.1 Stage 1

1) Enter the sample village.
2) Contact the village leaders (Village head/Kamnan), explain yield-per-rai survey objectives and Crop-Cutting methods, count and record the rice cultivation households that will gather harvest within the set time period, and obtain random samples of three households.
3) Contact the sample farm households, inform contact objectives, notify of yield-per-rai survey by means of Crop-Cutting, and request cooperation for interviews regarding various data required according to the questionnaire.

2.1.2 Stage 2

1) Random sampling
   Ask the sample households about the amount of plots capable of harvest within the set time period but only within the sample village vicinity; draw a location map of each plot. If there is no plot capable of harvest within the operational time period, ask each sample household when the harvest will take place for each plot in order to meet with the farmers again at a later date. If impossible to harvest any of the sample households, select the reserve sample households instead.
   Take random samples of one rice plot by applying the random sample chart (Table 1).

Table 1. Template for random sample

Total fields	Sample paddy no.	Total fields	Sample paddy no.	Total fields	Sample paddy no.	Total fields	Sample paddy no.
1	1	6	4	11	1	16	4
2	2	7	4	12	11	17	7
3	2	8	1	13	5	18	10
4	3	9	5	14	11	19	13
5	1	10	10	15	10	20	13

2) Random sampling of rice field plot
   - Enter the sample rice field.
   - Inquire of the sample farm concerning the total amount of plots and amount of sample plots; draw a map and allocate a number for each plot.
   - Obtain random samples from two plots applying the random sampling chart (Table 2).

Table 2. Template for random sample of square plots

Total amount of square plots	Sample plots		Total amount of square plots	Sample plots		Total amount of square plots	Sample plots	
	No. 1	No. 2		No. 1	No. 2		No. 1	No. 2
1	1	1	6	2	5	11	5	10
2	1	2	7	2	6	12	1	7
3	1	3	8	4	8	13	3	10
4	1	3	9	2	7	14	4	11
5	2	5	10	5	10	15	6	14

2.1.3 Stage 3

1) The crops must be harvested from the survey points established beforehand and must commence at the corner of each plot.
   - From the lower left corner of the sample plot, walk along the ridge to the top taking 30 steps, then turn right into the plot and take another 30 steps. This is Survey Point 1 (Figure 1).
   - For the other sample plot, start at the corner opposite the first sample plot, walk along the ridge downwards taking 30 steps, then turn right into the plot and take another 30 steps. This is Survey Point 2 (Figure 1).
   - Place a frame at each survey point measuring 1 m x 1 m; each side of the sample frame must be placed and built parallel to the ridge.
   - Gather crops from each stalk within the sample frame.

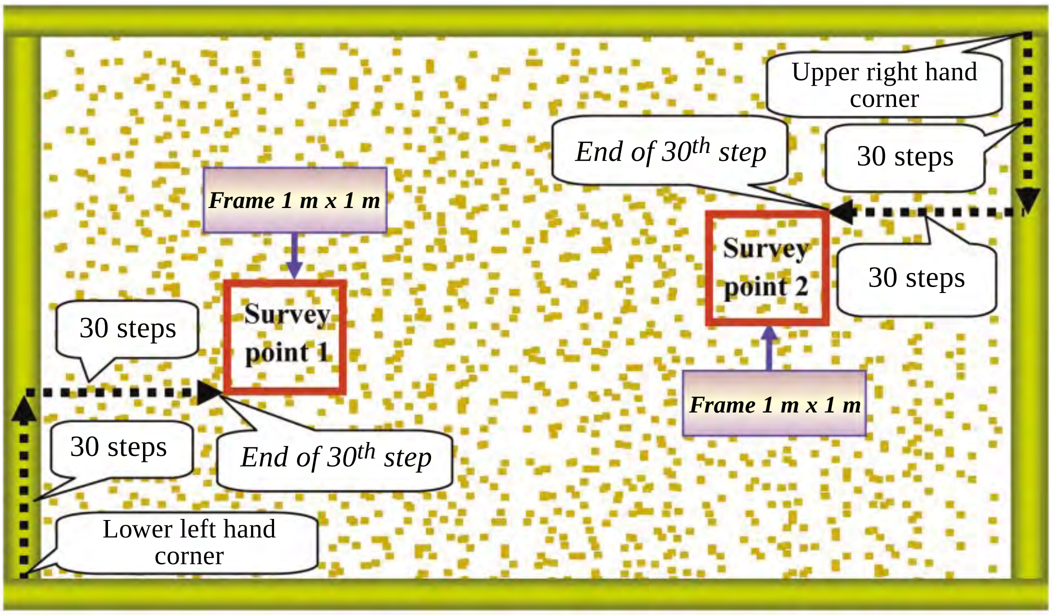


Figure 1. Crop-Cutting for sown fields in case of single plot or paddy

2) Harvest rice from two survey points and place into mesh bag; separate the crops from each survey point and record the details into the sign prepared beforehand.
3) Dry the rice in the sun for one to two days without removal from the mesh bag prior to delivery to responsible officers.

2.1.4 Stage 4

Deliver the sample rice harvested and the survey manual to officers at the Regional Office of Agricultural Economics (upon completion of survey at the sample village) within the time and date set beforehand.

2.1.5 Stage 5

Inquire into the actual yield after all three sample households have completed their harvest; this inquiry may cover the entire rice field.

2.2 Work operations of regional office of agricultural economics officers

Officers at the Regional Office of Agricultural Economics must complete 6 stages for the rice yield-per-rai Crop-Cutting Survey as follows.

2.2.1 Stage 1

Conduct the yield-per-rai survey by means of Crop-Cutting at certain sample villages applying the same methods implemented by the Office of Agricultural Economics and closely supervise the Office of Agricultural Economics.

2.2.2 Stage 2

When the manuals and survey forms have been obtained from the Office of Agricultural Economics, verify the implied data accuracy and integrity.

2.2.3 Stage 3

When the rice crops harvested from the sample plots have been obtained, proceed as follows (Figure 2):

1) Thresh the rice using the semi-automatic rice thresher provided by JICA,
2) Weigh,
3) Measure the moisture level. The purpose of moisture measuring is to estimate marketing yield by revising raw crop cutting yield. The rate of moisture content of rice should be used to adjust the yield. The enumerator measures the moisture content of the sample grains and revises the weight of rice based on the moisture content. The standard moisture content in Thailand is 15 percent.
4) Record data into the survey form.

Figure 2. Threshing, weighting and moisture measure

2.2.4 Stage 4

Follow-up the post-harvest survey results and record into survey form.

2.2.5 Stage 5

Record data into the ready-made software via website for further processing.

2.2.6 Stage 6

The data processing results will appear at the central access point for each data sample recorded.

2.3 Yield-per-rai estimation and analysis

The final stage includes estimation, analysis, and presentation of yield-per-rai by means of Crop-Cutting survey results performed by the Centre for Agricultural Information.

2.4 Operational Work Procedures include the following:

1. Centre for Agricultural Information obtains the data via internet on the website from the Regional Office of Agricultural Economics.
2. Carefully verify the accuracy, integrity, and completeness of data obtained from the Regional Office of Agricultural Economics by taking all data implications and possibilities into account.
3. After examining the data, the Centre for Agricultural Information will process the data obtained from the Regional Office of Agricultural Economics once again.
4. The final survey results (survey result table and details) will be implemented by the Regional Office of Agricultural Economics for analysis and consideration together with wastage crops from the harvest and areas not cultivated.

3. Gleaning survey

Presently, harvesting machinery is popularly used in every region, especially the Central region, because of problems related to lack of available labour and high wages. Thus, farmers turn to rice harvesting machinery solutions which offer a convenient and fast alternative despite exorbitant wages.

However, significant ensuing problems include wastage of rice crops left remaining in the cultivation area by the various harvester machinery; the time period; and moisture during the harvest cycle. As a result, the calculations obtained from the yield-per-rai survey by means of Crop-Cutting reaches a higher yield value than actually realized by the agriculturalists. Therefore, to calculate a precise and credible yield-per-rai value, it is necessary to survey the aforementioned wastage rice crops.

The method of a harvesting loss survey is basically the same as a Crop-Cutting Survey. We select the same paddy fields which have harvested at random in the Crop-Cutting sample villages, and select survey spots, then set up a 1 m^2 frame. Next we glean the rice grains remaining within the frame in the sample fields. When we conduct the harvesting loss survey, we do it before ducks, mice, geese, buffalos, etc. come into the sample field. Those bring us non-sampling errors.

4. Dyke survey

A dyke survey is the survey for measuring the area of the non-planted area or special area if the non-planted area located within those cultivation area contains ponds, trees, molehills, barns, etc. The data of the real planted area must directly include the rate of non-planted area in order to adjust the Crop-Cutting data.

We conduct Crop-Cutting within the sample field which excludes the dyke area. In the case of paddy crop cutting, we set up the 1 m^2 frame on the rice field where rice is cultivated. Then we cut, weigh and estimate the yield. Therefore, the estimated yield does not include the dyke area.

The dyke survey consists of 2 parts. First is to measure the planted area with the dyke. In this case, we use the tape measuring method because this method is very easy to measure a paddy field. The tape measuring method consists of a combination of 2 techniques. One is to use Heron's method. Another one is to use the offset (plus minus) method.

The second part is to measure the dyke area. The method is very simple. We measure the length and width of the dyke and then we multiply them.

Experiences of crop cutting experiments in Bangladesh for annual yield estimation of rice

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Key words: BBS, SID, DAE, SPARRSO, NSO, CCE, UNFAO

ABSTRACT

Bangladesh is predominantly an agrarian country. The geographical condition is favourable for growing vast quantities of different types of agricultural products. Rice is the most important agricultural product in consideration of coverage of area and production. The total production of rice was 3.38 million in 2012-13 FY. There are three rice seasons. The internal consumption demand for rice is also high for a population of more than 15 million. Agricultural production statistics are highly important for the government food policy, including exports and imports. Bangladesh has a long history of producing reliable agricultural statistics to the government, international organizations and other stakeholders. As the supply and demand in the country is high, the government has to import rice when production falls due to natural calamities; the production situation goes under critical assessment. With a view to critically analyzing the production estimation procedure, an integrated approach was undertaken by the government. The Bangladesh Bureau of Statistics (BBS) under the Statistics and Informatics Division (SID), Ministry of Planning produces annual agricultural production estimates as the National Statistical Organization (NSO). The Department of Agriculture Extension (DAE) under the Ministry of Agriculture prepares monitoring data in a subjective manner. The Space Research and Remote Sensing organization, another government agency, provides area estimates of two major rice crops. These three organizations with their concerned Ministries took part in the integrated assessment process.

Under the support of the Harmonization and Dissemination of Unified Production Statistics project, which is on-going with technical and financial support from the Food and Agriculture Organization of the United Nations (FAO), BBS conducted 400 Crop Cutting Experiments (CCE) in two different districts. This was done with the joint participation of BBS and DAE officials, using both crop cutting methodologies used by BBS (99.40 sq. feet) in a circular shape and DAE (20 sq. meter) in a rectangular shape. However, the statistical findings were that when the size of the crop cutting is smaller, the higher the tendency of overestimation and the circle method provides less Coefficient of Variation (CV) due to less boundary effect. These findings are supported by many experiments done earlier in India. It again upholds the idea that if the size of the plot of crop cutting is much lower than 170-180 sq. feet, there will be a possibility of overestimation. And the circular cutting will provide less CV than the rectangular cutting having the same plot size or cutting area. After a critical analysis of the findings of the Experimental Crop Cutting, the crop cutting plot size having 20 square meters (215 278 square feet) with a circular shape was accepted. This will eliminate over or underestimation on the one hand and less boundary effect as well as non-sampling error due to less perimeter (2.15 meter less) on the other. The minimum sample size (50 CCE) per district is also determined and a new crop cutting schedule and manual have been provided. A uni-stage sample design is followed and a total of 10 347 clusters are used as the sampling frame (area frame) for selection of the plot. The CCE of new methodology is being implemented jointly at the field level by BBS and DAE officials, which has minimized the gap among stakeholders and increased the knowledge on estimation.

1. Background

Bangladesh is predominantly an agrarian country. The geographical condition is favourable for growing vast quantities of different types of agricultural products. Rice is the most important agricultural product in consideration of coverage of area and volume of production. The total production of rice in 2012-13 FY was 3.38 million m. tons. Bangladesh is the fourth largest rice producing country in the world. There are three rice seasons in Bangladesh. The internal consumption demand for rice is also high for more than 15 million people of the country. Hence, agricultural production statistics are highly important for the food policy of the government, including policies related to exports and imports. The Bangladesh Bureau of Statistics (BBS) has a long history of providing reliable agricultural statistics to the government, international organizations and other stakeholders. As the supply and demand in the country is high, the government has to import rice when production falls due to natural calamities. As a result, the production situation goes under critical assessment. The Ministry of Food assesses the requirements of food (rice and wheat) and facilitates the government regarding availability of food and making export and import decisions. BBS produces annual agricultural production estimates as the National Statistical Organization (NSO) using the sampling methodology. DAE, under the Ministry of Agriculture, prepares monitoring records in a subjective manner and the Space Research and Remote Sensing Organization (SPARRSO), under the Ministry of Defense, provides area coverage of two major rice crops on the basis of satellite imageries. These data from different sources did not always match, which created confusion among the stakeholders. To avoid this sort of confusion among government agencies a consensus among the Ministry of Planning, Ministry of Agriculture and Ministry of Food was made on the concept of harmonization. After that, the Harmonization and Dissemination of Unified Agricultural Production Statistics (HDUAPS) project, with technical and financial support from the Food and Agriculture Organization of the United Nations (FAO) was undertaken by the BBS. The national and international consultants of the project undertook activities to critically analyze the existing methodologies used by BBS, DAE and SPARRSO and organizations and recommended statistically sound methodology for yield estimation of rice. These three organizations with their concerned ministries associated with the integrated assessment process.

2. Methodology

Under the support of the HDUAPS project, BBS conducted 400 Crop (rice) Cutting Experiments (CCE) in two districts in the country. As it was decided by the Technical Committee of the project that as DAE has no sample design to select sample crop cutting plots, the plot selection can be done on the basis of the clusters (area estimates) formed and used by BBS for area and yield estimation of crop. One hundred crop cutting experiments using a plot size of 99.40 sq. feet with a circular shape were used in each district earlier by BBS, and another 100 crop cutting experiments were conducted in the same plot using a plot size of 215.278 sq. feet (20 sq. meter) with rectangular shape by DAE. As a result, a total of 200 CCEs were conducted in each district. More than 30 plots were fully harvested after conducting two CCEs. This gigantic task was done with the joint participation of BBS and DAE field officials. During field operations high officials from concerned agencies and ministries along with consultants visited the field work to ensure the quality of experiments.

3. Results obtained

The data of 400 CCEs were analyzed and some extraordinary results were found which are shown below:

Table 1. Statistical Findings obtained from Crop (rice) Cutting Experiments

Name of Districts	Standard Error	Rectangular Shape (215.278 sq. feet earlier used by DAE)	Circular Shape (99.40 sq. feet earlier used by BBS)
Rajshahi District	Standard Error	44.61694	45.66414
	Coefficient of Variation	2.825875	2.793431
	% Over/underestimation	6.30741	10.6702
Barisal District	Standard Error	30.69389	30.92711
	Coefficient of Variation	2.970418	2.921049
	% Over/underestimation	- 2.352276	0.05259

In the table, it is evident that for both shapes, overestimation is found only in Barisal District in the case of the rectangular shape. But it proves that in plots smaller than 200 feet there is a higher tendency to produce overestimation. This result of the investigation confirmed the previous experiments done earlier in India (Mahalanobis 1945; Sukhatme 1947a). However, another important finding of these experiments is that the circular shape provided less Coefficient of Variation (CV) in both the districts due to less boundary effect, though the Standard Error for the rectangular shape is less. The result of this experiment also implies that the circular cutting will provide less CV than the rectangular cutting having the same plot size or cutting area. This is because of the smaller perimeter of the circular plot than the rectangular plot. For example, for a 215 sq. feet plot area, the perimeter of a circular shape will be 15.8533 meters and 18 meters for a rectangular shape, which is 2.1467 meters less. Due to a smaller perimeter in the same plot size, the border effect will be less as well as the non-sampling error. Consequently, it will provide less CV. After critical analysis of the findings of the Experimental Crop Cutting, the crop cutting plot size having 20 square meters (215.278 square feet) with a circular shape was recommended by the project. The uni-stage sample design was recommended with a sample size of 50 Crop Cutting Experiments per district. There will be 50 x 64 districts = 3 400, whereas previously it was 10 x 487 upazilas = 4 870. As a result the cost will be minimized and the district-wise level of precision will be also be provided. This will eliminate over- or under-estimation. A total of 10 347 clusters are used as sampling frames (area frames) for the selection of plots. The CCE of the new methodology is being implemented jointly at the field level since 2013 by BBS and DAE officials. This has minimized the conflicts on annual rice production estimates and increased the knowledge of users on estimation. The crop cutting instrument provided by the project can be graphically shown in Figure 1.

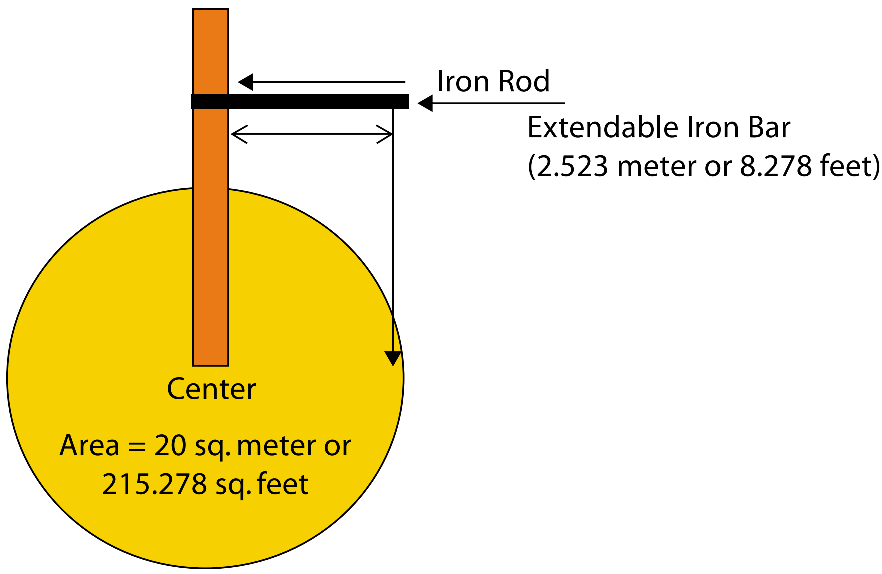

Figure 1. Graph of Experimental Crop (rice) Cutting Instrument

4. Conclusions

The need for a statistically-sound methodology to provide production estimates for rice is extensive in Bangladesh because of the vast production and high internal demand. The consensus regarding this issue among the stakeholders is also very important for policy making. The new methodology was well discussed among the stakeholders and they are aware of the estimation process, so there is no confusion about production estimates of rice. On the basis of the new methodology, everybody will know the reliability of estimates. The data collection according to new methodology is being implemented by BBS and DAE, which can be considered the best practice among the ministries to work jointly and solve important national issues.

5. Success achieved and issues for further research

Rice production in Bangladesh is high, so obtaining reliable data through the recommended methodology is really a great success of the project of the Government of Bangladesh and FAO. The issue has been finally settled after the large experiment carried out under the joint ownership and effort of the Government and FAO. This example of joint activities among ministries can be followed and may solve many critical issues of the government which concern more than one Ministry. As there are many agricultural products that grow abundantly in Bangladesh, this type of experiment can be done in the country for many other temporary and permanent crops.

References

Mahalanobis 1945; Sukhatme 1947a.

The agricultural survey improvement program in Islamic Republic of Iran

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Key words: Application of Remote Sensing, GIS & GPS Technology in agricultural statistics, Multiple Frame Agricultural survey, crop monitoring

ABSTRACT

To improve agricultural statistics in Iran, the Ministry of Jihad-e-Agriculture (MOJA) requested assistance from FAO in order to improve agricultural statistics programmes which are practical and can produce reliable, timely and cost effective information. The development objective of the project was to establish a methodology for a new National Program of Agricultural Surveys that would produce twice a year the basic national and provincial level data for the agricultural sector.

The immediate objectives of the project were to design and implement an Annual Agricultural Survey in Hamadan Province, using a multiple frame survey design with two survey rounds per year. The statistical design procedure has been based on Cochran (Sampling Techniques, third edition 1977) and the Multiple Frame Agriculture Surveys (volumes 1 and 2; FAO Statistical Development Series number, 7 and 10). Remote sensing (RS), Geographical Information Systems (GIS) & Global Positioning System (GPS) Technologies have been used to implement the project.

The main objective of the project was the design, demonstration and applicability of more advanced methods of producing reliable, timely and cost effective agricultural statistics, as well as training the required staff and providing training material for its implementation. Although the agricultural statistics produced in the course of the project was not timely and therefore could not be effectively used in the management process, the technology that was used to produce it was well demonstrated. The project demonstrated that the new design is capable of producing more reliable, cost-effective and timely agricultural statistics in Islamic Republic of Iran.

1. Background

Iran adopts a decentralized system in agricultural statistics. Different governmental departments undertake statistical activities individually in the areas for which they are responsible. The Ministry of Jihad-e-Agriculture (MOJA) and the Statistical Centre of Iran (SCI) were the two major organizations for agricultural statistics.

The SCI is responsible for the agricultural census and national aggregates. The Bureau of Statistics and information Technology (BSIT) is responsible for crop and the cost of production, livestock, fishery and forestry surveys.

The MOJA obtains its primary data on crop areas and yields through three major activities:

a. Production forecasts;
b. Agriculture data assessments; and
c. Crop monitoring and direct measurements.

Every year through the above activities the MOJA forecasts crop and fruit production levels in early spring. Later, in the fall, the actual production levels are assessed and if more accurate data are needed, direct measurements and remote sensing techniques are applied.

Production forecasts: By mid-spring the Ministry reports its forecasts on production levels for decisions to be taken on food-balance, import-export policies, guaranteed price polices, etc. The forecasting is based mainly on time-series analysis and expert's observations throughout the country at the provincial level. Observational reports on areas planted, weather reports and input distribution reports are the main sources of information for these forecasts. There are no standard procedures or guidelines for provincial agricultural departments to carry out this task. Each province reaches a conclusion based upon its experts and managerial perceptions. By the end of March, all provinces send their reports to the relevant organization or deputy in the MOJA in Tehran. All the provincial forecasts are then aggregated in collaboration with the relevant experts to derive the national figures. Since there is no coherent procedure written and implemented for deriving this forecast, the figures reflect compromise rather than reality; therefore, the figures are not reliable and usually are highly misleading. There is no specific budget allocated for this forecast and it does not involve any kind of formal data acquisition. This process takes between two to three months each year.

Agriculture data assessment: Detailed agricultural statistics are produced through sampling surveys every year after harvest in the fall. Four data collection projects are carried out throughout the country in this respect. Each project has its information system with well-defined procedures and manuals. Three projects are designed to assess production and the fourth one for detailed farming system data. These projects are:

- wheat and barley sampling project;
- rice and certain crop sampling project;
- other crops sampling project;
- detailed farming system sampling project, called "Cost of Production" system.

In addition, occasionally BSIT conducts case specific surveys for particular items, such as potatoes and orchards in some parts of the country. Agricultural statistics are also generated through the reporting systems, which are mainly based on local statistics and expert judgments.

In 1995, a research contract was signed between the BSIT and the International Institute for Aerospace Survey and Earth Sciences (ITC) of The Netherlands to design and develop a proper method which can generate timely and reliable information on the area and production of the major agricultural commodities in the selected province. Such methods could be later upgraded to cover the entire national territory. The project was called "Development of crop inventory and forecasting system for the major agricultural commodities in Hamadan Province, Islamic Republic of Iran". The project activities started in March 1995 and were completed by May 1998. The main objectives of the project were formulated as follows:

- Development of crop inventory methods and procedures;
- Development of yield forecasting method;
- Development of a crop forecasting method; and
- Development of a conceptual model for the crop forecasting system.

Crop area estimation was making use of area frame sampling (square segments) and remote sensing techniques. The area frame sampling performed quite well in all aspects, e.g. it costs less; it is more timely; and it produces better results. As it is based on measurements rather than interviews, technically it was also well understood and could be easily operationalized at different extents.

The yield estimates made use of crop growth simulation models which use extensive data sets on crop phenology, physiology, soil, weather and management practices. In the absence of the real data for many of the required parameters, a reasonable estimate as a default value was applied in the simulation procedures.

The yield components, due to its detailed information requirements, did not produce a satisfactory forecast of the production of the major agricultural commodities. So BSIT continued the crop forecasting concept by using crop growth simulation based on new satellite technology called "Surface Energy Balance Algorithm for Land" (SEBAL).The SEBAL is an image-processing model comprised of 25 computational steps that calculate the actual (ET_{act}) and potential evapotranspiration rates (ET_{pot}) as well as other energy exchanges between land and atmosphere. This methodology is under examination and the results will be presented later.

In 2000, based on BSIT's request, FAO sent a mission to Iran in order to advise on the establishment of a new national program to improve agricultural statistics based on more advanced survey methods to be installed through a pilot test in Hamadan Province. In this context, an agreement between the Government of the Islamic Republic of Iran and the Food and Agriculture Organization of the United Nations concerning technical assistance services for the agricultural survey improvement program was prepared and signed in 2004. The project was called "Agricultural Survey Improvement Programme (ASIP)". This time a combination of Area Sampling Frame (ASF) and List Sampling Frame (LSF), which is called Multiple Frame sample surveys (MFS), has been used. This paper describes the implementation of MFS methodology.

2. Study area

The study area was the province of Hamadan, Islamic Republic of Iran. It is located in the western part of the country and covers 2 021 426 hectares (Figure 1). The area consists of high (3 500 m) mountains, hilly areas and plains. In the plains, irrigated agriculture is predominant, though there are substantial salinized areas. In the hilly areas dry farming (mainly wheat and barley) is practiced and also grassland and natural vegetation is present. The mountains are mainly covered by natural vegetation and grassland with (small) valleys where agriculture is practiced (mostly irrigated). The area has a semiarid climate with mild summers and very cold winters. The mean annual rainfall ranges between 320 and 350 mm, and mean monthly temperature varies from – 5°C in January to 24°C in July. The soils of Hamadan Province are predominantly of clayey texture and the litology is determined by calcareous schist and limestone. The major crops in the area are wheat, barley, alfalfa, potato and beans. Wheat and barley that cover 80 percent of the area are considered as the major crops in the region.

Figure 1. Location of study area

3. Methodology used

The statistical design procedure has been based on Cochran (Sampling Techniques, third edition 1977) and the Multiple Frame Agriculture Surveys (Volumes 1 and 2; FAO Statistical Development Series numbers 7 and 10). A conceptual presentation of the survey design is shown in Figure 2.

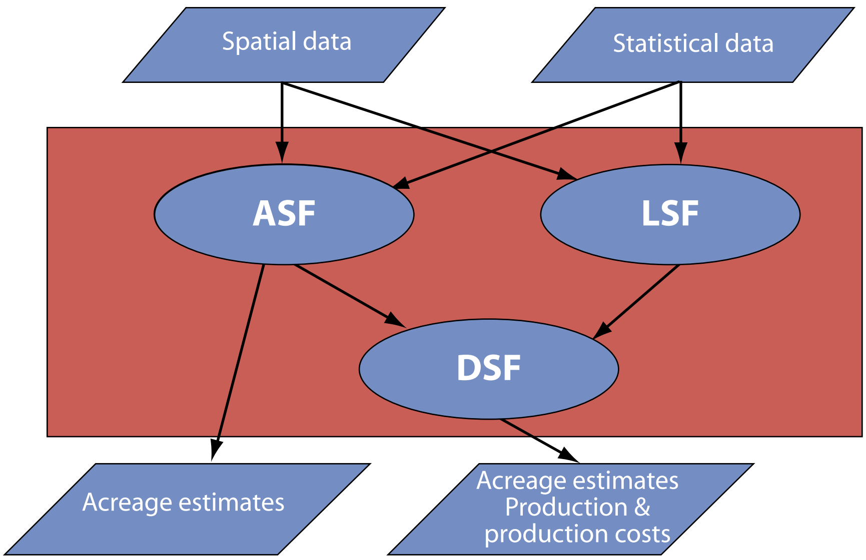

Figure 2. Conceptual presentation of the survey design

In the course of the design, the following activities have been carried out:

- Establishment of a stratified map of the province. Considering the existing land use maps and manual photo interpretation of recent satellite images (IRS-WIF, 180 meter resolution acquired on September 2005, and 2005 SPOT-5 images) the project area has been stratified to irrigated agriculture, rainfed agriculture, orchards, rangeland, non-agriculture, and urban. Next the area of each stratum has been measured.
- Selection of sample size and sampling rate in each stratum: Sample size and rate in each stratum has been selected based on the importance and variability within each stratum, tradeoffs (ratio) between input (cost, and resources) and output (accuracy). In this process, first the sample size for each stratum had been selected and then based on the required sampling rates the number of so-called "Secondary Sampling Units (SSU)" in each stratum had been identified. As a result, 181 "SSU" had been selected (Table 1).
- PSU and SSUs sizes had been decided as following: for rangeland stratum, a SSU was equal to 100 ha, and PSUs from 1 000 to 2 000 ha. For rainfed land the average size for SSUs was 50 ha and PSUs from 500 to 1 000 ha. In the irrigated land, the SSU has been around 25 ha and PSUs from 250 to 500 ha. Finally, the average SSU for orchards was 20 ha with PSU average size varying from 200 to 400 ha.

Table 1. The area of each stratum and its related total and sampled number of SSUs

Stratum	Area(ha)	Number of SSU's	SSU size (ha)	Sample rate	Number of selected SSU's
Range	428 085	4 281	100	0.004	16
Rainfed	814 256	16 285	50	0.005	81
Irrigated	376 137	15 045	25	0.004	64
Orchards	50 498	2 520	20	0.008	20
Non agriculture	352 450	0	0	0	0
Total	**2 021 426**				**181**

- Establishing Prime Sampling Units: The sample units (SSUs) in different strata have been distributed over each stratum through larger units, so-called Primary Sampling Units (PSU). Each PSU, contains 10–20 SSU's. Next, PSUs were manually delineated on a Land Sat-ETM Ortho photomap containing the stratified boundaries as well as administration boundaries. Delineation has been carried out by local experts after proper training, based on natural and physical boundaries. PSU boundaries have been entered into a GIS (digital database) and prepared for sample selection.
- Identification of the selected prime sampling units: To distribute the selected number of samples in the study area, a replicate sampling method has been applied. The replicate number has been coordinated with the desired sample rotation. The samples were drawn in a way that is evenly distributed over the stratum. After selection of PSUs in each stratum, their boundaries have been transferred into a geometrically corrected (1/10 000 scale) 2005 Spot-5 images with 10 meter resolution. For orchards the 1/5 000 enlargement of the IRS-Pan image (with 6 meter resolution) has been used. In this process the boundaries have been adjusted to the natural and physical boundaries (Figure 3).
- Identification of Second Sampling Units "SSUs". In this process, each selected PSU has been divided into 10-20 SSUs, (the size of SSUs for different strata). Delineation of SSUs in each PSU has been carried out considering the size and natural boundaries. Next, SSUs have been numbered and a sample has been randomly drawn. The SSUs are units that have been used for field work; therefore, they have been well defined and documented.

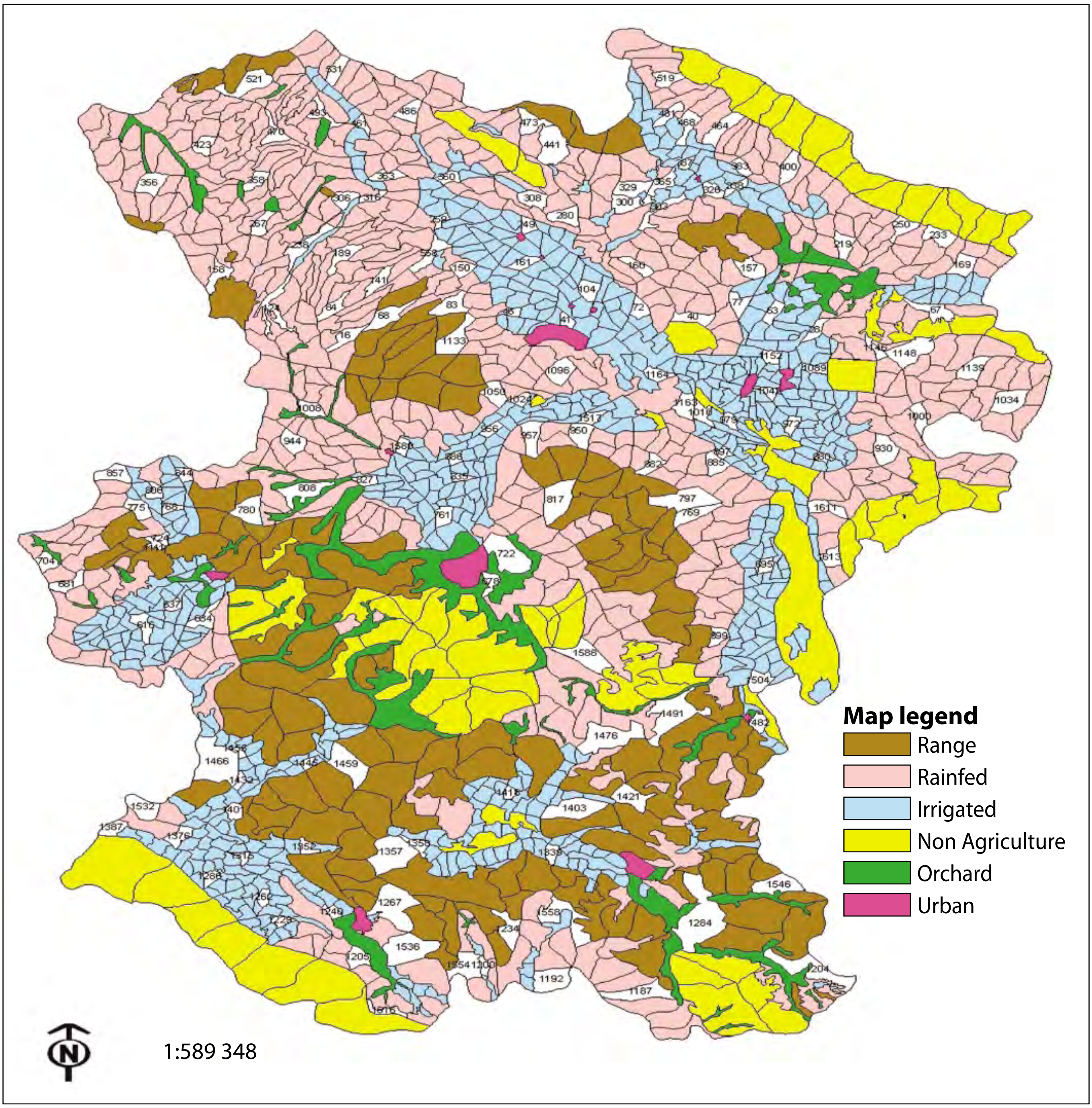

Figure 3. Selected PSUs of Hamedan Province

- Definition of selected SSU samples: The boundaries of selected SSUs have been transferred to existing IRS 1-D. 1-C Pan Images, and printed on the 1/5 000 scale paper (Figure 4). Using the hard copies, the boundaries of the SSU were further adjusted to the natural boundaries. For orchards, to achieve better visibility it had been decided to use the enlarged 1996 aerial photographs. The aerial photographs have been first scanned, geometrically corrected and used for the process.

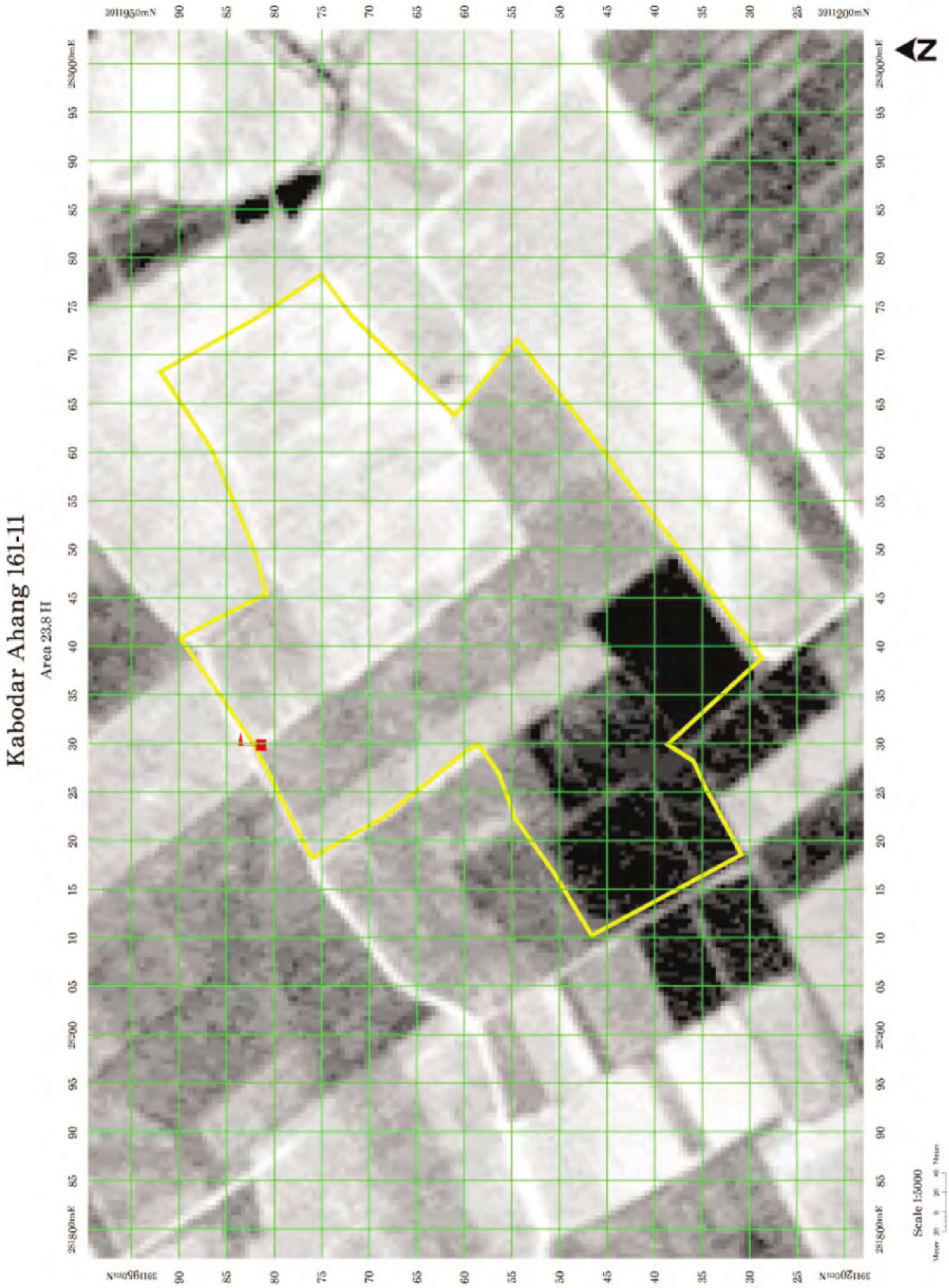

Figure 4. Selected SSU ortho-photomap (IRS 1c panchromatic image, scale 1: 5 000)

- A complete kit per enumerator had been prepared containing maps and images of different scales, instructions for finding, establishing, and completing questionnaires and data collection, and finally a hand-held GPS for navigating and locating the segments. To facilitate the data collection process, the kit also included an enlarged colour-composite spot image map showing the distribution of SSUs, map of selected PSU, plus the 1/10 000 colour image and 1/5 000 scale black and white images of a selected SSU.

The area frames have been used for different items; mainly annual crops, orchards, and livestock. However, an area frame alone could not ensure good results for livestock or for rare and concentrated items. Therefore, for some of the items, such as livestock, a mixed frame (list + area) has been applied. In order to combine both frames, a list of large livestock holders had been prepared and a decision has been made to interview all farmers who own more than 100 heads of cow and calf or more than 500 heads of lamb, sheep and goats. A separate list of names had been prepared and given to the enumerators to check during the survey to identify those holders that are on the list and operating in the sample units. Clear instruction had been given to remove all the large farmers from the area frame since they will be enumerated exhaustively while the small holders will remain related to the sample units where they operate. According to the importance of livestock in the country and the accuracy requirement, the weighted segment has been preferred for use instead of open segment.

All the above processes have been mainly carried out by the local experts after short face-to-face training and on the job training.

3.1 Field work and data collection

The field data collection started after control of the SSU, PSU, definition, documentation and preparation of questioners, forms, codes, and instructions. That included the following main activities:

- Field work training: A period of 5 days of field work has been carried out to verify and improve the training given to the field crews to make sure that the field organization can carry out the data collection and data quality assessment, and validate and improve the instructions, forms, and developed procedure.
- In the survey design, two rounds of data collection had been foreseen. One for collecting data on areas and livestock and one for production and other economic items. Since the first round had been delayed due to the unavailability of new satellite data, it was decided to carry out the two rounds as follows:

  First round:
  - Postpone the field data collection of the orchards stratum for one month.
  - Collect data on area for all holders.
  - Collect data on production just for holders who have harvested their fields before the survey day.
  - Collect data on livestock for the holders who operate within the unit and have less than 100 heads of cows or less than 300 of sheep/goats.

  Second round:
  - Concentrate on larger operators who have more than 100 heads of cows or 300 heads of sheep/goats.
  - Collect data on production for the remaining holders who had not harvested their fields during the first round.

3.2 Data processing quality assessment

According to the original plan, the data processing should have been completed by December 2006, which should have allowed quality assessment and documentation to be finalized by January/February

2007. Due to some administration problem, the links between FAO experts and project implementation were cut until April 2009. Naturally this delay caused significant impacts on the effectiveness and efficiency of the project as organization, quality control, and processing of the collected data had been disturbed. The FAO experts in their last mission (April 2009) had reviewed the design and implementation of sampling ASF including data collection, data entry and processing, survey results and had made an overall assessment of the project, with special attention to the documentation of processes by the Iranian counterparts.

3.3 Documentation

One important element of the project has been documentation, which includes basic theory and principles, development of a proper manual for sampling design, field work and data processing. In addition to the provided text book, a manual has been developed by the Iranian experts. This has been considered important as it documented the process as has been understood by the Iranian experts.

4. Results obtained

Estimates were made for each stratum. Some strata give more accurate results because of variations in sample rate. Here, only the combined estimate for the province is given.

Three main results were expected: crop areas estimates, crop productions estimates and livestock estimates.

To estimate crop areas and crop production, a closed segment method was used due to the precision provided at different levels (stratum, province). However, for livestock estimates, a weighted segment method was preferred because the reporting unit here is the holding.

The outcome of data analysis doesn't include the crop production estimates due to the difficulty found in the processing data section to supply data. The same was true for the orchards stratum; neither areas nor crop production estimates as well data were processed. So, the outcome can be divided into two sections accordingly: area estimates and animal husbandry estimates.

4.1 Crop areas estimates

The total area for all strata considered under the present study in Hamadan Province is estimated to be 697 307 hectares where the cereals represent a major proportion (74 percent). Table 2 shows details of area estimates by crop in Hamadan.

Table 2. Area estimates for crops in Hamedan Province

Crops	Total in irrigated land	Total in rainfed land	Total in range land	Total in province
Wheat rainfed	34 622	261 957	47 941	344 521
Wheat irrigated	77 186	19 278	1 838	98 302
Barley rainfed	11 824	12 840	14 852	39 516
Barley irrigated	25 395	5 417	171	30 983
Maize	3 060	965	0	4 025
Potato	17 965	348	166	18 479
Beans	784	84	0	869
Alfalfa	50 137	5 919	3 644	59 701
Other silage	4 274.38	4 607	8 147	17 029
Other crops	25 719	30 431	27 733	83 883
Total	**250 958**	**341 847**	**104 493**	**697 307**

4.2 Animal husbandry estimates

The total of all animals (for all strata) actually counted is given in Table 3. Cattle, sheep and goats were counted in all strata but the major proportion is represented by sheep (86 percent) while the cows and goats both don't exceed 14 percent.

Table 3. Results of animal husbandry survey (Hamadan Province AFS 2006)

Strata	Cow	Sheep	Goat
Irrigated agriculture	62 060	597 231	40 568
Rainfed agriculture	52 863	1 210 020	117 183
Rangelands	22 475	377 795	44 147
Orchard	12 941	94 372	9 942
Large holders	5 020	3 807	65
Total in Hamadan Province	**155 359**	**2 283 225**	**211 905**

Since it was the first application of the weighted segment, regarding the way data has been processed and the unavailability of some input about a number of strata, the number of households interviewed before stratification, the limit of cut off of each stratum, etc., we could not ensure whether the results were correct enough unless we reprocessed all the data, re-checked everything and had all the missing input to do the analysis. It should be understood that particularly for livestock there was no way to check data as it should be according to the number of mistakes related to shared production system, the data processing system and the data base system.

5. Conclusions

The evaluation of the whole survey work in Hamadan Province through the final survey findings were good enough to ensure technically that the extension of this new methodology to other regions would be without any risk or particular problems. However, decision makers have to determine when and where the extension of this new methodology should be and make sure to have the necessary facilities and staff competency for processing data and building a good data base system.

The working team has a good methodological knowledge, even though there is still a need for technical assistance to supervise different activities. The project has achieved its objectives despite the use of old materials such as satellite data acquisition, aerial photography during the preparation phase.

Based on the information collected during the survey, data analysis of the field samples and evaluation of the current stratification, it is highly recommended that a complete stratification may become necessary which can be achieved through application of new satellite data. This will help to establish a better frame and land use strata.

Due to lack of time it was not possible to control the production and orchard data and there are no estimates for crop production or orchards area. This means that the final results will be underestimated even for crop areas and livestock, as the cropped area in the orchard strata is not included.

Considering the BSIT's and regional field office competences, the test had met its objectives and the new survey sampling system (dual frame) can be expanded to other provinces as well as to the national level in the future. The results will be more satisfactory for the users since the areas will be assessed through measurement procedures instead of the household declarations and the productions will be based on the weight from selected plot cutting crops. The new surveys system will provide the means to the BSIT to have areas and productions precisely measured and good statistics on livestock as well.

6. Issues in application of RS, GIS & GPS Technologies in agricultural statistics and proposed solutions

A. The most important issue is availability and accessibility of remotely-sensed data. Because of international sanctions against Iran, ordering and purchasing satellite data is very difficult. So we need to list and organize existing data and apply them for similar projects in the MOJA. In this regard, two main activities have been done:
   1. Activating a council of RS & GIS users of the MOJA in order to coordinate RS-GIS activities and decreasing implementation of parallel projects.
   2. Design and development of a spatial data clearing house by MOJA in order to inform data users of existing data such as satellite data, aerial photographs, topographic maps in different scales, thematic maps, GIS information layer and so on.

B. Regarding international sanctions against Iran, purchasing RS/GIS software is very difficult so the council of RS and GIS users of the MOJA in coordination with the national council of GIS Users decided to change to open source RS and GIS software.

C. To support decision makers and planners, establishment of a system for crop monitoring and forecasting is essential. Dual frame sampling surveys are capable of producing reliable information on area and production, but don't produce any maps, so a combination of DSF with modern digital image processing for producing precise spatial statistics is a field for future research. Also application of RS, GIS and crop growth simulation models to monitor and forecast crop production is another field for future research. As mentioned before, the MOJA is testing use of the SEBAL model and will report the results soon.

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Application of spatial information technology to crops production survey in the NBS of China

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ABSTRACT

Spatial Information Technology (SIT) includes remote sensing, GIS and GPS. SIT is used to aquire, manage and analyse information with spatial characteristics, provide full coverage and give accurate positioning.

In 2006, the National Bureau of Statistics (NBS) launched a national project "Research on Key Technology and Application of National Statistical Sensing Operational System." The main content of the project is the crop production survey. Other applications include a population census, economic census and an investment survey. The paper focuses on the application of SIT to crop production surveys.

To reform the crop planted area and yield survey methods, and to further improve production data quality for the main crops such as wheat, rice, corn, cotton, and oil, the National Bureau of Statistics lays out three goals, namely 1) enhancing the quality of statistical data; 2) the statistical capacity; and 3) the public credibility on official statistics. Information on the major grains (wheat, rice and corn) is strengthened by using the space technology. Based on experiences from the pilot planted area surveys on crop production conducted in 2011 and 2012, the NBS decided to officially begin the area frame sample surveys in 2013 in five provinces, namely Jiangsu, Henan, Liaoning, Jilin, and Hubei.

1. Sampling design

1.1 Data sources of sampling frame

Sources of the area sampling frame have the following aspects. Number one is from the Second National Agricultural Census (SNAC, 2006). The information on planted crops from SNAC is more complete. However, SNAC doesn't have spatial information and the timeliness of the data is also a concern. The second source is the results of the Second National Land Survey (SNLS, 2007-2009). Although it had more complete spatial information of the cultivated land, there is a lack of crop information. The third source is the results of the high-resolution remote sensing imagery which had more recent main crop information, but its coverage did not meet the need. On the other hand, low and middle resolution remote sensing imagery might meet the coverage requirement, but they did not have the accuracy to identify the crops. So, the remote sensing imagery could not be used directly but could be used as an auxiliary variable for the sampling design. Therefore, we need to make best use of data from different sources to compile the sampling frame.

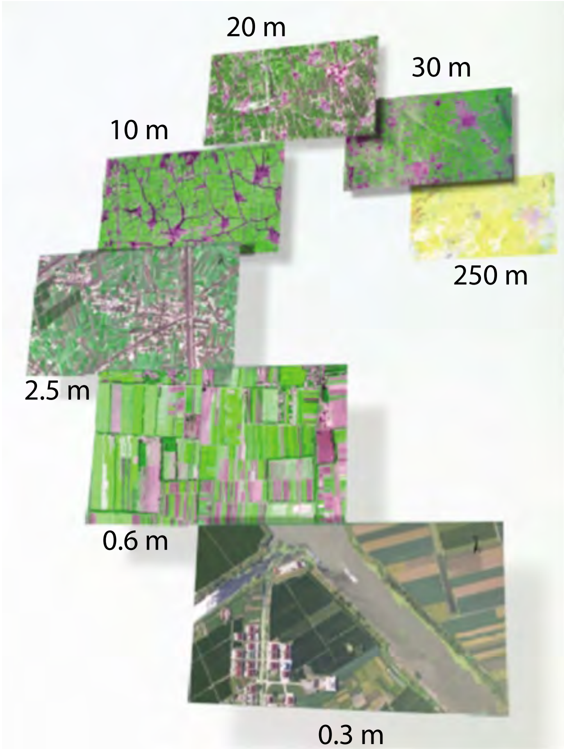

Figure 1. Resolution remote sensing images

1. 2 Compiling sampling frame

The Elementary Sampling Unit (ESU) for the planted area of the crop production survey should be directly investigated by interviewers. It is important to determine the area size of the ESU. The following aspects should be taken into account: structure of the crop planted; the natural boundaries of arable land; and the workloads of the interviewers. After considering these factors, we set the area size of the ESU in Jiangsu and Hubei at two hectares (30 "mu"), while in Liaoning, Henan, and Jilin it was set at five hectares (75 "mu"). We adopted an approach of multi-stage sampling to select samples of ESU. We compiled the sampling frame for PSUs by combining the data of boundaries among the administrative villages from SNLS and planted areas of crops for respective administrative villages from both updated high resolution remote sensing imagery and the SNAC. For some provinces with enough high definition imagery, such as Jilin Province, we used a spatial grid to replace the administrative villages as PSUs. The sampling frame of the ESU is derived from the PSU samples.

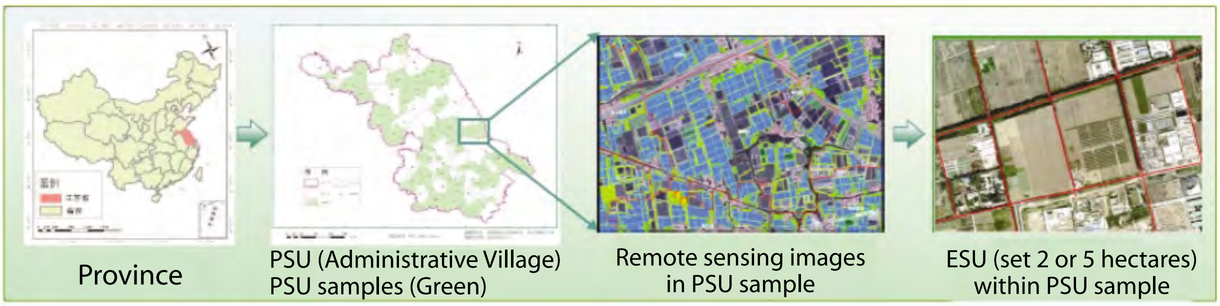

Figure 2. Setting PSU and ESU

1. 3 Process of samples selection

1. 3.1 Selection of samples for planted area

A multi-stage sampling approach was adapted to select samples of the planted areas. At the first stage, we used PPS (Probability Proportional to Scale of cultivated land) to select samples of PSU (administrative villages or spatial grid), which were stratified according to the structure of the planted crops. The CV for major grains (wheat, rice and corn) and cotton was set below 5 percent. While determining the number of samples for specific provinces, workloads and survey costs were taken into account. At the second stage, the SRS (Simple Random Sampling) approach was used to select ESU samples from the PSUs. First, the boundaries of the ESU were drawn on the spatial vector diagram based on the area size of the ESU mentioned above (2 or 5 hectares). Second, the ESU was numbered by spatial position. Finally, 3-5 ESU samples were selected by using the SRS approach.

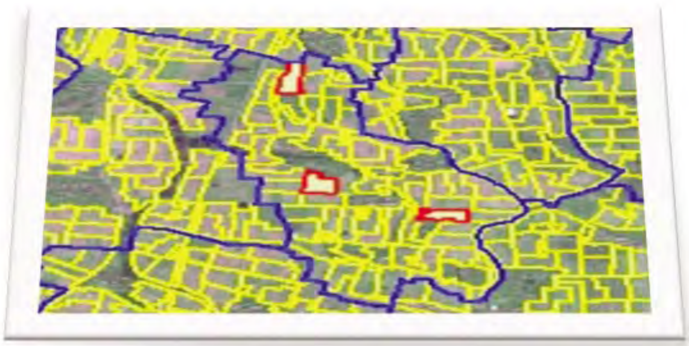

Figure 3. ESU (yellow) and ESU samples (red)

1. 3.2 Selection of yield samples

A two-phase sampling approach was adopted to select yield samples: 1) Data collection for yield estimation. In the crop production harvest season, yield was estimated for crops planted on the ESU samples. 2) Selection of yield samples. The ESUs were queued based on the yield estimation of the target crop (wheat, rice, corn, etc.). Then, samples were selected at a 1/3 ESU sampling ratio. Relative error coefficients for target crops were controlled to less than 2 percent. If the sampling error did not meet the requirements, it would be necessary to increase the number of yield samples. 3) Field survey on yield. During the harvest period, interviewers selected 3-5 segments randomly within the yield samples to cut and measure the actual yield for each crop.

2. Data collection

GPS + PDAs were used to collect data in the field survey. At the beginning of the field survey (the ESUs registration), we used GPS and PDAs to find, position and measure ESUs. During the planting and harvest seasons, GPS and PDAs were used to measure the planted areas of the target crops.

For the yield survey, traditional tools such as sickles, rules, ropes and platform scales were still used to collect the yield of crops.

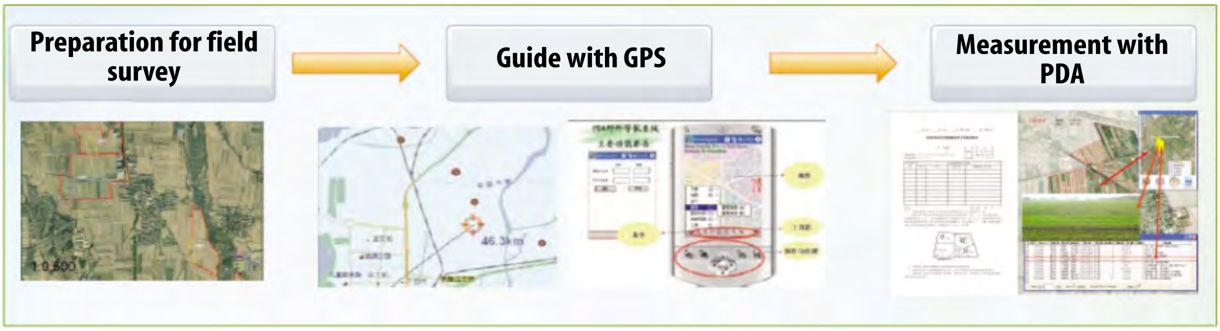

Figure 4. Field survey with GPS+PDA

3. Data quality control and assessment

While carrying out the field survey, UAVs (Unmanned Aerial Vehicles) were used to recheck the planted areas of the ESUs, and a Positioning Monitoring System was used to control and supervise the activities of interviewers in real-time and synchronously. The digital images captured during the field survey are part of the new approach to control and assess data quality.

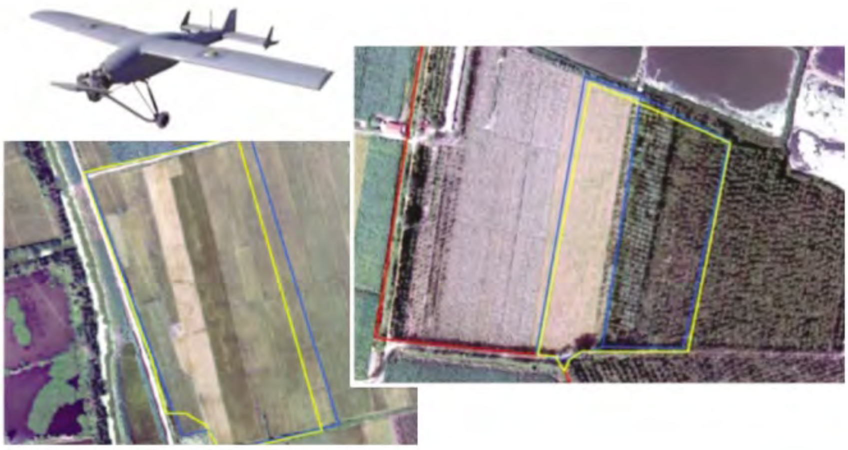

Figure 5. Recheck planted area with UAV

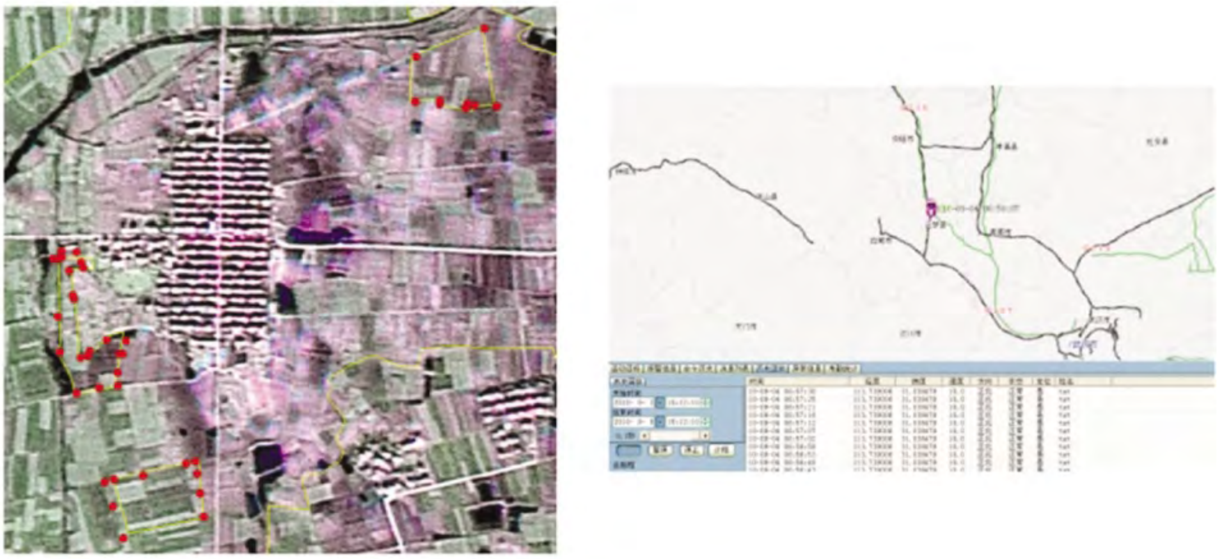

Figure 6. Data Quality Control and supervision real-time

The jackknife method is adopted to calculate sampling error assessment of planted areas for all the target crops. The specific steps are as follows:

1) The sample is stratified by village groups to sort through the equidistance method; the sample is then assigned to R non-overlapping groups.
2) For each group (identified by r) the complement of a knife called a first group of sub-samples r (Replicate).
3) For the sample layer h i, is defined as:

$$w_{i(r)} = \begin{cases} w_i n_h /(n_h - n_{hr}) & \textit{when "i" in the "r" th jackknife subsample} \\ 0 & \textit{other (when "i" in the "r" th group)} \end{cases}$$

4) When a continuous statistic variable $\hat{\theta}$ is calculated by the w_i estimator, the estimated amount of each sub-sample $\hat{\theta}_{(r)}$ by a set of its own $w_{i(r)}$ calculated the packet Jackknife (DAG) MSE estimator is:

$$\hat{V}_{DAGJK}(\hat{\theta}) = [(R-1)/R]\sum^{R}(\hat{\theta} - \hat{\theta}_{(r)})^2$$

Like the above formula as MSE estimators usually called "Packet Jackknife estimator", usually set R = 15, the confidence interval of 14 degrees of freedom using the student's t distribution.

Accordingly, the relative standard error for the sample is as follows:

$$CV(\hat{\theta}) = \frac{\sqrt{\hat{V}(\hat{\theta})}}{\hat{\theta}}.$$

After the actual test, the CV of the target crop plant is less than 5 percent.

4. Estimation for variables of population

Target crop planted areas of population are calculated by using the ESU samples' extension weight which is the reciprocal of the sampling probability. The formula is as follows:

$$\hat{X} = \sum_{i=1}^{m}\sum_{j=1}^{n_i} x_{ij} w_{ij} w_i$$

In the formula, x_{ij} is target crop planted area of ESU samples, and w_{ij} is the extension weight from the ESU sample to the PSU sample, and w_i is the extension weight from PSU sample to population (at the provincial level).

Target crop yields of population are the simple average of actual yields of ESUs. The formula is

$$\hat{\bar{y}} = \frac{1}{n}\sum_{i=1}^{n} \bar{y}_i .$$

5. Conclusion

1. Through application of SIT to the crop production survey, the completeness and timeliness of the sampling frame was improved greatly and the cost of updating the sampling frame decreased as well.
2. The efficiency and accuracy of the field survey were increased greatly by using GPS, UAV and PDAs.
3. The means to contral data quality are more effective through using a real-time monitoring system.
4. The data quality for major crops is improved greatly and better meets the needs of data users, especially for agriculture policy-making.

Methodology development for estimating sago stock by using area frame in West Papua, Indonesia

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Key words: Spatial Statistics, Area Frame Sampling, Remote Sensing, Sago Palm

ABSTRACT

Sago palm belongs to the Genus Metroxylon, Family Palmae, and a characteristic is the accumulation of a huge amount of starch in its stem. An invaluable resouce of starchy food, sago palm could play an important role in respect to possible food shortages in the world in the future. Sago palm is a tropical plant which not only grows in the dry lands but also grows with high adaption to low-lying wetlands such as fresh water swamp, peat swamp or brakish water. The origin of sago palm is believed to be the area extending from the Moluccas and Papua of Indonesia to New Guinea. However, the attention given to exploring the potential of sago stock has not been adequate in Papua. The objective of this study is to develop a spatial statistics method for mapping and estimating the sago stock in Inanwatan District, Sorong Selatan Regency, West Papua. Area frame sampling of square segment method is applied for estimating sago stock, which involves: 1) stratification of study area by using high resolution of satellite data; 2) design of a sample frame survey; 3) field survey for ground truthing; and 4) data analysis. The results show that the total study area is 13 315 ha consisting of 2 892 ha of non-sago forest and 10 423 ha of sago forest. Sago forest is divided into 3 strata, namely low density, medium density, and high density, which have an area of 630 ha, 392 ha, and 9 401 ha respectively. The population of ripe sago palm in low density, medium density, and high density is 22 680 stands, 32 928 stands, and 549 018 stands equal to 4 930 tons, 7 226 tons, and 109 044 tons of sago starch, respectively. So the total sago stock in the whole study area is 121 200 tons of sago starch.

1. Background

Sago palm belongs to the Genus Metroxylon, Family Palmae, whose members accumulate a huge amount of starch content in the stem (Flach 1997) and is a significant source of raw material of high economic value (Abd-Aziz 2002). Furthermore, Ave (1977) said that sago palm has been described as man's oldest food plant. Contrary to its important role in economic and cultural aspects for a hundred years (Oates 1999), currently sago palm is still an underutilized plant.

It is estimated that Indonesia has 1 398 000 hectares of sago palms; of which 1 250 000 hectares are sago forest growing wildly and 148 000 hectares are cultivated sago palm. Meanwhile, Papua an island belonging to Indonesia, has 1 200 000 hectares of sago palm forest and 14 000 hectares of cultivated sago palm (Flach 1997). Ngudiwaluyo *et al.* (1996), referring to several sources, state that Indonesia has only about 1 million hectares of sago palm, whereas Kertopermono (1996) estimates 1.5 million hectares, but both researchers agree that 90 percent of Indonesian sago palm is in Papua (including West Papua). In West Papua, sago palms have been reported to exist mainly in low-lying marshlands and wetlands of southwestern Manukwari (Figure 1). Among the local people of West Papua, part of the sago palm and its product is utilized as food stuffs in those areas while the rest are exported to other regions.

Figure 1. Physical visualization of sago forest environment in West Papua

Interest in this palm species has increased considerably in the last three decades because of its advantages of being economically acceptable, relatively sustainable, environmentally friendly, uniquely versatile, vigorous, and it promotes socially stable agroforestry systems (Stanton 1993). In Indonesia, the sago palm has recently gained interest, especially as one of alternatives for subsitution of staple food in respect to national food security. However, information on its present location and distribution is missing, and it cannot be ascertained whether there is enough supply of sago to drive and sustain a large scale sago starch industry.

The objective of this study is to apply a spatial statistics method to estimate the sago stock in West Papua (Figure 2). High resolution Geo-eye satellite data is employed to stratified sago palm forest, and an area frame survey is constructed for deriving field data of sago palm. The location of the study is in the ANJ Agro Annual Work Plan Area, South Sorong, West Papua.

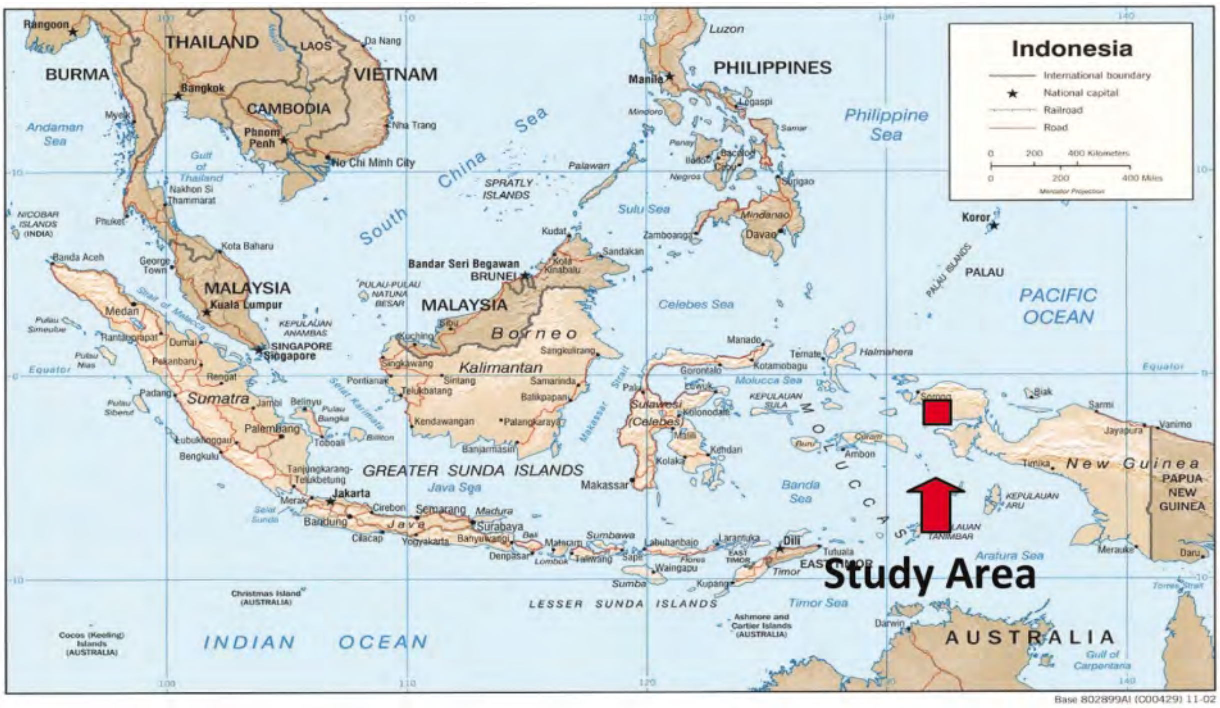

Figure 2. Location of study area

2. Methods

Figure 3 shows the overall flowchart of activities starting from preparation up to data analysis. There are three main activities to estimating sago stock in the study area: 1) developing area frame sampling; 2) a ground truthing survey; and 3) data analysis. The following discussion is a more detailed description of each work.

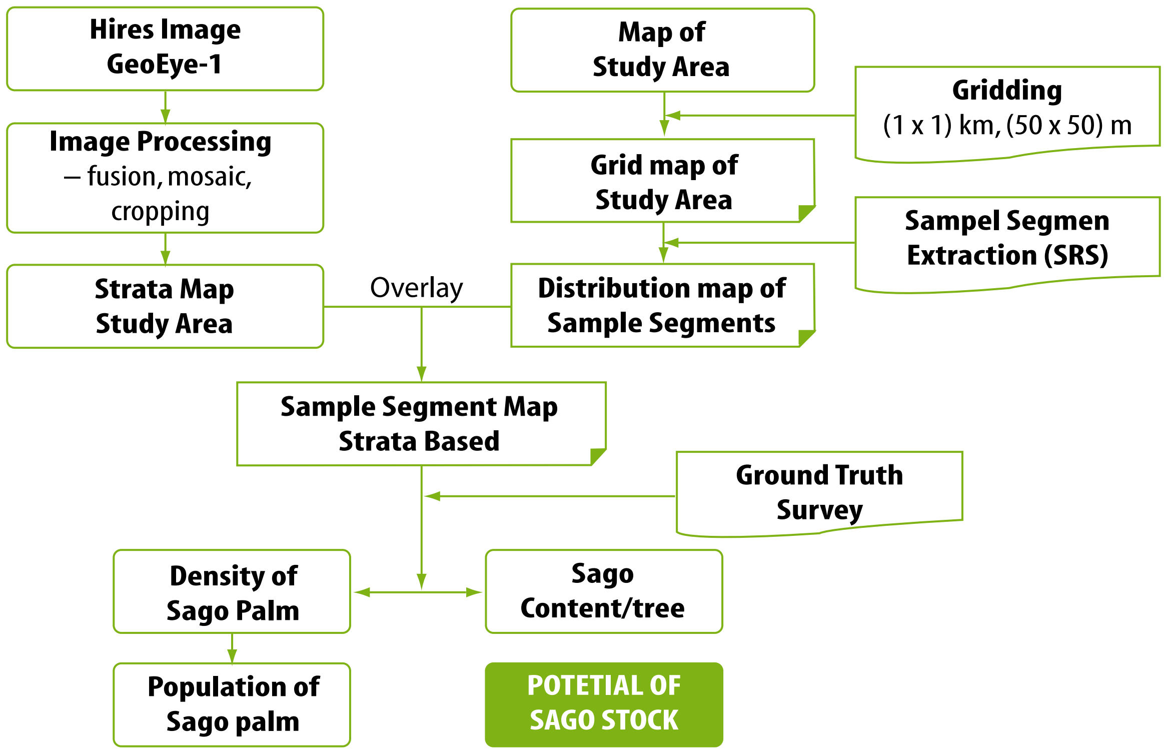

Figure 3. Flowchart of activity to estimate sago stock in South Sorong

2.1 Developing area frame sampling

The sago forest inventory in South Sorong regency, West Papua will be done by area frame sampling of square segments. Rules-based spatial statistics are used in the construction of the sampling frame. The stages of the contruction includes stratifying the study area, defining sample size, and extracting sample segments.

Stratification of study area

Stratification is the division of a population Ω of size N into H non-overlapping subpopulation Ω_h (strata) of size N_h. The closer the behaviour of the N_h elements within each stratum, the more eficient the stratification (Gallego 1989). In this research, the study area is stratified into 4 catagories based on domination of sago palm canopy interpreted from satellite data, namely:

- Strata-0: Non-Sago Forest;
- Strata-1: Low Density (domination of palm canopy around 1-30 percent);
- Strata-2: Medium Density (domination of palm canopy around 30-60 percent);
- Strata-3: High Density (domination of palm canopy around 60-100 percent).

A tool for stratifying the study area is high resolution satellite (Geo-Eye) data from 2012 and 2013. Interpretation of satellite data is conducted by on screen delination. It is explained by Sutanto (1986) and

Bahri (2011) that the key to interpretation of sago palm data is recognized by star canopy with 10 m length, irreguler pattern, and growing in low land.

Definition of sample size

Definition of sample size refers to the guidence of forest inventory by the Ministry of Forest (2007), where the number of the sample size is defined to have error level of 5 percent and the size of the sample segment is 0.25 hectares. The mathematical formula to count the sample size is as follows:

$$n = \left(\frac{CV\%}{SE\%} xt \right)^2 \tag{1}$$

where,
n = sampel size
SE = Sampling Error (5 percent)
CV = Variance of volume from the average (percent)
t = Convidence level of 95 percent (t value close to 2)

The Ministry of Forest states that Indonesian forests have 65-75 percent variance of volume based on the empirical data. By the asumption of 80 000 hectares of forest consessions, the size of the sample segment is around 0.2-0.3 percent. The size of the sample segment in this research is defined as 0.5 percent of the study area, that is assumed to meet the 5 percent error level.

Extraction of sample segment

The sampling frame of a square segment sized 50 m x 50 m is used for extracting a sample segment so that it is necessary to convert a digital map of the study area from a vector map into a grid map. The statistical rule applied to extracting a sample segment is SRS (Simple Random Sampling) in order to have a good spatial distribution of selected sample segments. GIS software is employed to process spatial-based digital maps. To do so, the first step is to divide the study area into a large grid 1 km x 1 km in size and then divide those grids into smaller subgrids 50 m x 50 m in size, so that one large grid consists of 400 small grids. The second step is to go to the first large grid (upper left) and randomly select a small grid sample segment of 0.5 percent. The third step is to copy the selected sample segments pattern and paste it to the other large grids. To know the distribution and number of selected segments in each stratum, it is necessary to overlay the strata map and the extracted sample segment map. Each selected sample segment has its own identity such as stratum, geographical coordinate and number of randomization. The identity of the selected segment is important for not only ground surveying but also field data processing.

2.2 Ground-truth survey

A ground-truth survey conducted for each selected sample segment aims to derive parameter data of quantitative densities and starch contents of sago palm. Even though, high resolution satellite images are available, GPS is the only a tool to find the exact location of each selected sample segment because of difficulties in finding physical features of sago palm forest on the image.

The parameters of sago palm density measured from each sample segment are the number of bunched (RS) and number of growing stages, namely before mature stage (BMT), mature stage (MT) and after mature stage (LMT). Sjahrul in Bintoro (1999) states that there are six growing stages of sago palm, namely shoot, seedling, sapling, before mature stage, mature stage, and after mature stage. But in this research, we observed only the last three growing stages for the research objectives. Whereas, parameters of sago starch content are to measure diameter of trunk at breast height (Dbh) and midrib free height

(Tbp), the measurement of diameter and height are only for mature trees because that stage is considered to contain sago starch.

2.3 Data analysis

Density estimate

Density of sago palm forest is the average of sago stand per hectare for each growing stage, i.e. Before Mature Stage (BMT), Mature Stage (MT), and After Mature Stage (LMT). The mathematical formula to count sago palm density is as follows:

$$\bar{y}_h = \frac{1}{a}\frac{1}{n_h}\sum_{i=1}^{n_h} y_{ih}$$

Where,
$\bar{y}_h$ = sago palm density (stand/ha) in strata,
a = area of sampel segment,
n_h = total of sample segment in strata h,
y_{ih} = total sago stand in sample segment ith strata h

Population estimate

Sago palm population is calculated by multiplying sago palm density (stand/hectare) and area of strata (hectare). The mathematical formula is as follows:

$$Z_h = A_h \bar{y}_h$$

Where,
Z_h = population in strata h,
A_h = area of strata h (hectare)

The result of the population count in each strata is used to calculate the total population of sago stands in the whole study area using the formulation below:

$$Z = \sum_{h=1}^{H} Z_h$$

Where,
Z = population of sago palm in the whole study area,
H = total number of strata

Sago stock estimate

The content of sago starch in each tree refers to previous research conducted by Yumte (2008) in South Sorong, West Papua. Those research generate a correlation between diameter at breast height and midrib free height and sago starch content. The correlation is described by the mathematical formula below:

$$W_s = 1{,}792\left(D_{bh}\right)^{0{,}648}\left(T_{bp}\right)^{0{,}874}$$

Where,
Ws is fresh weight (kg/tree), Dbh is breast height diameter (cm), Tbp: midrib free height (m).

Based on the above equation we can calculate the fresh weight of each tree inside the sample segment since field data of breast height diameter and midrib free height are obtained. Then, the next step is to calculate the average sago content in each stratum by the formula below:

$$\overline{W}_{s_h} = \frac{1}{n_h}\sum_{i=1}^{n_h} W_{s_{hi}}$$

Where,

$\overline{W}_{s_h}$ is the average sago content per tree in strata-h (kg/tree),

n_h is number of sampel segment in strata-h,

$W_{s_{hi}}$ is the average sago content in strata-h, sample ith (kg/tree).

The potential of sago in each stratum is calculated by multiplying the total population and the average of sago content per tree. The formula is as below:

$$P_h = \frac{1}{1000} Z_h \overline{W}_{s_h}$$

Where,

P_h is the potential of sago in strata h (ton)

Finally, the estimation of sago stock in the study area can calculated by using the formula below:

$$P = \sum_{h=1}^{H} P_h$$

Where,

P is the potential of sago stock in the whole study area.

3. Results and discussion

3.1 Contruction of area frame sampling

Stratification of the study area is generated by interpreting GeoEye satellite data acquired on January 2013. GeoEye is one of high spatial resolution data, where multispectral reflectances have 1.65 m spatial resolution, and panchromatic reflectance has 0.41 m spatial resolution. Data fusion for combining multispectral and panchromatic data was applied to enhance its interpretability where the color is derived from the multispectral and the sharpness derived from panchromatic (Figure 4).

Figure 4. Satellite data fusion; (a) Multispectral, (b) Panchromatic, and (c) Data fusion

Since sago trees have specific star canopy on the image, it is easy to recognize and differentiate between sago and non-sago forest. A strata map then can be obtained by on screen delineation of the data fusion image for whole study area (Figure 5). The areas visually interpreted as non-sago forest are stratified into Strata-0, whereas the areas visually interpreted as sago forest are stratified into strata-1, strata-2, and strata-3.

- Strata-1 is defined as Low Density forest which has 1-29 percent of sago palm
- Strata-2 is defined as Low Density forest which has 30-59 percent of sago palm, and
- Strata-3 is defined as Low Density forest which has 60-100 percent of sago palm

Based on the strata map, the extracted study area is 13 315 hectares consisting of 2 892 hectares strata-0, 630 hectares strata-1, 392 hectares strata-2, and 9 401 hectares strata-3.

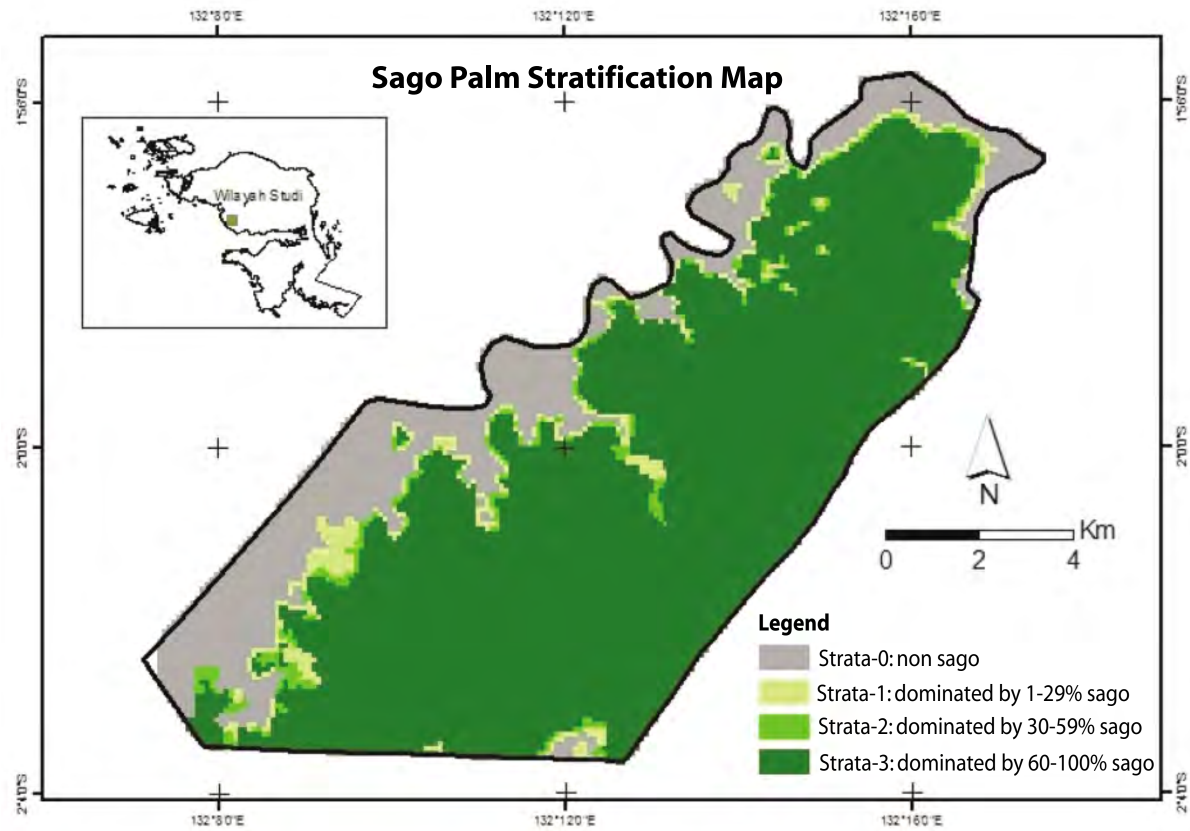

Figure 5. Result of sago palm stratification in the study area

Area sample frame construction is done to set the field data collection strategy in each stratum. GIS Software is an effective tool to process a digital map for producing an area sample frame. Sample segments are selected in stratum-1, level-2 and level-3 only, while sample segments in stratum-0 (non-sago forest) are eliminated. Systematic random sampling rules are used to extract 0.5 percent sample segments, then the extracted sample segments are overlaid on the strata map. The total selected sample segments in the study area are 208 segments, where 119 segments fall in strata-3, 56 segments fall in strata-2, and 33 segments fall in strata-1 (Figure 6).

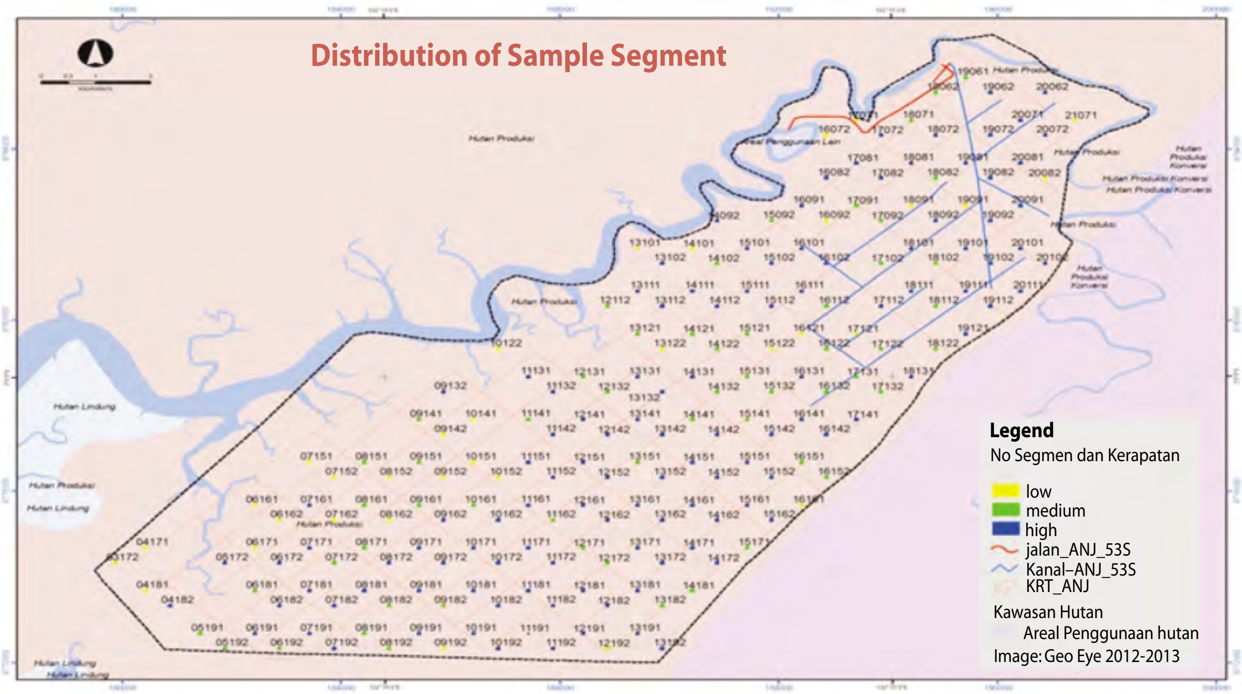

Figure 6. Distribution map of sample segments in each strata

3.2 Ground-truth survey

A ground-truth survey is conducted to observe all extracted sample segments as shown in Figure 4. The main tools to reach a desired sample segment are a map of high resolution image and GPS. The map is used as a road-guide for approaching the segment based on physical fixtures on the image, such as river, canal, settlement, road and so on. After closing on the segment, GPS is very useful to find the exact location of the segment.

Parameters of sago palm density measured from each sample segment are the number of bunches (RS) and number of growing stages, namely before mature stage (BMT), mature stage (MT) and after mature stage (LMT). The parameters for estimating sago starch content are found by measuring the diameter of trunk at breast height (Dbh) and midrib free height (Tbp). The measurement of diameter and height are only for mature stages, because those stages are considered to contain sago starch.

Heavy constraints were found when entering sago forest because of the very high dense forest and deep swamp. A part of the field data has been done but the other part is still in progress. Based on the field observation, sago forest has a low variance of sago population, so that it is considered to have a smaller size of sample segment than 0.5 percent. In general, sago forest is located several kms from the main river and under a flooded water environment.

3.3 Data analysis

The overall results of the data analysis is summarized in Table 1. It is to note that collecting field data is still in progress so that the data in Table 1 below is still temporary results. RS density in each stratum is 40 bunch/ha, 44 bunch/ha, and 63 bunch/ha for strata-1, strata-2, strata-3, respectively. These results indicate that quantitative density with respect to the field data analysis is a match to qualitative density with respect to the image interpretation. Sago palm density in strata-1 and strata-2 is quantitatively not significantly different, but the density of strata-1 and strata-2 is remarkably different compared with the density in strata-3. Total RS in each strata is 25 200 bunches, 17 248 bunches, and 594 143 bunches, so that it produces 636 591 bunches in the whole study area. We can find growing stages of sago palm inside each bunch, namely before mature stage (BMT), Mature Stage (MT), and After Mature Stage (LMT).

Table 1. The result of density, population and sago stock estimation in the study area

Parameter	Unit	Strata-1	Strata-2	Strata-3	Whole Area
Area	(ha)	630	392	9 401	10 423
RS	Density (bunch/ha)	40	44	63	
	Population (bunch)	25 200	17 248	594 143	636 591
BMT	Density (tree/ha)	52	72	80	
	Population (Tree)	32 760	28 224	752 080	813 064
MT	Density (tree/ha)	36	84	58	
	Population (Tree)	22 680	32 928	549 018	604 626
LMT	Density (tree/ha)	16	36	26	
	Population (Tree)	10 080	14 112	240 666	264 858
Sago Content	Average (Kg FW/tree)	2 174	2 194	1 996	
	Sago Stock (Ton FW)	4 930	7 224	109 584	121 200

The results of the field data analysis show that the density of BMT in each strata is 52 trees/ha, 72 trees/ha, and 80 trees/ha for strata-1, strata-2, and strata-3, respectively. The population of BMT in each strata can be calculated by multiplying the density and its corresponding area. The result is 32 760 trees, 28 224 trees, and 752 080 trees for strata-1, strata-2, and strata-3, respectively. The total population of BMT in the whole study area can be derived by adding up the population in each stratum, i.e. 813 064 trees. BMT is not ready to harvest yet, and it needs around 2 years to harvest. Such BMT population data is important to manage harvest rotation and predict sago starch potential to harvest in the future.

MT density in each stratum is 36 trees/ha for strata-1, 84 trees/ha for strata-2, and 58 trees/ha for strata-3. Similarly, the calculation results of the the MT population are 22 680 trees, 32 928 trees, and 549 018 trees for strata-1, strata-2, and strata-3, repectively. So the total MT population for the whole study area is 604 626 trees. MT is the only growing stage which is ready to harvest due to its sago starch content. MT population data is used to estimate sago starch production at the present time.

LMT density in each stratum is 16 trees/ha, 36 trees/ha, and 26 trees/ha for strata-1, strata-2, and strata-3, repectively. The calculation of LMT population produces 10 080 trees, 14 112 trees, and 240 666 trees, for strata-1, strata-2, and strata-3, respectively. The population of LMT in the whole study area is 264 858 trees. The LMT population indicates that the sago palm should be cut in order to increase starch yield.

As mentioned in the methodology the starch content in each tree refers to the correlation between diameter at breast height and midrib free height and sago starch content. Of course, the correlation between diameter, height and sago starch content depends on local specific environtments, such as soil, terrain, and climate where the sago palm grows. Based on those field data of diameter and height, we can calculate the average starch content/tree in kg fresh weight (kg FW). Table 1 shows that the yield of sago starch/tree in strata-1 and strata-2 is much higher than the yield in strata-3, indicating the less the density of the sago forest the higher the yield of sago starch. The yield of sago starch/tree in the study area is much less compared to the yield in the Meranti Islands District. It is reported by Balitbang Pertanian (2013) that the average yield in Meranti Islands can reasch 398 kg/tree. The stock of sago starch in each stratum then can be obtained by multiplying the average starch content/tree and its corresponding population. The potential of sago stock is 4 930 ton FW, 7 224 ton FW, and 109 582 ton FW for strata-1, strata-2, and strata-3, respectively. The final estimation of sago stock in the whole study area is 121 200 ton FW.

4. Conclusions

1. Data fusion of high-resolution satellite imagery between panchromatic and multi-spectral is very useful for visual interpretation to differentiate non-sago forest and sago forest.
2. Spatial statistics is an effective tool to develop area frame sampling for implementing field survey strategy
3. The size of the sample segment could be reduced by the fact that sago forest is more homogenous compared to normal tropical forest
4. Sago palm density in strata-1 and strata-2 is quantitavely not significantly different, but the density of strata-1 and strata-2 is remarkably different compared with the density in strata-3.
5. At the time of the survey, there were 813 064 trees ready to harvest 2 years later; 604 626 trees ready to harvest; and c) 264 858 trees of unutilised resource
6. Potential stock of sago starch at the the time of the survey is 121 200 tons

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Crop yield estimation surveys in India

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1. Introduction

The significance of reliable information on agricultural production is particularly high for the countries like India where agriculture continues to play an important role for food and livelihood security of a large population. Crucial decisions relating to procurement, distribution, price, export, import and the monitoring growth of the sector largely depend on crop production data. Generation of these statistics for the diverse agriculture, operated on an area of about 160 million hectares, requires a systematic statistical exercise.

The subject of Agricultural Statistics revolves around its two main parameters, namely Area Statistics and Yield Statistics. The statistics on crop area are generally captured in the land utilization statistics, with detailed statistics relating area sown under different crops in different seasons. On the other hand, yield statistics deals with productivity of sown crops in a particular year or a season. The estimates of crop production are derived from the product of crop area and the crop yield estimates. Since the agricultural activities are dependent on the agro-climatic conditions and for a large country like India, these conditions are divergent across its length and the breadth, the collection of data requires large scale sample surveys, assimilating the diversities in its coverage.

The crop yield estimation in India is one such elaborate statistical exercise, that has transited from a traditional system of eye estimation to a scientifically designed and detailed survey operation, under which nearly a million crop cutting experiments (CCEs) are annually conducted on 68 food and non-food crops. The present paper provides salient features of this elaborate statistical exercise.

2. Evolution of general crop yield estimation survey in India

The system of area statistics and yield statistics in India is generally dovetailed with a well established land revenue system having systematic records of each field (survey number) based on periodically updated cadastral surveys of the villages. While Land Use Statistics (LUS) are a comprehensive and systematic account of natural endowment of land spanning over 328 million hectares of geographic space of the country, crop statistics assimilate the diverse agro climatically-influenced crop acreage and production details of numerous crops, grown over a 142 million net sown area with about 135 percent cropping intensity.

Prior to the introduction of the scientific method based on statistical sample survey, estimates for crop yield and production were built up through the traditional annawari system. This system is essentially a judgment by designated knowledgeable persons. Under this method, the yield per hectare is obtained either in terms of a direct estimate in quintals per hectare by eye-appraisal or as the product of what is called the "normal yield" and the "condition factor".

The scientific methodology on estimation of acreage and production and evolution of crop cutting experiments based on objective sampling methods was the seminal contribution of

Prof. P.C. Mahalanobis[27] of the Indian Statistical Institute during 1937-41. Prof. V.G. Panse and Dr P.V. Sukhatme[28] of the Indian Council of Agricultural Research (ICAR)[29] also made a very significant contribution in 1942-48 by developing crop cutting methodologies for estimating the yield rate of cotton and wheat. Their approach was largely adopted for the Crop Estimation Survey in India, for estimating yield per hectare of principal food and non-food crops. The advantage of this method is that the representative estimates are available along with the estimated sampling error, enabling assessment of the precision of estimate. Since 1953, the Agriculture Statistics Wing of the National Sample Survey Office (NSSO) took over the role of central coordination of GCES including guidance to the federal states on survey design and documentation of the results.

The traditional method of estimation of crop production by eye–estimation has been gradually replaced by the scientific assessment through crop cutting experiments conducted under the GCES and forms the basis of estimation of the yield rate and the official production estimates of principal food and non-food crops. GCES is aligned with the statistical system for land use and crop acreage statistics, that is anchored on a long standing administrative land records system prevalent in the majority of the federal States of the country. In a few States, where such a system did not exist, alternative systems were put in place for crop acreage statistics.

Presently, crop estimation surveys are conducted in 29 States/UTs, including three non-land record States. The surveys cover a total of 68 crops comprising 52 food and 16 non-food crops, including nine fruit and 14 vegetable crops. Over 95 percent of foodgrain production is estimated on the basis of yield rate obtained from scientifically planned CCEs conducted under the programme of crop estimation surveys.

3. Features of crop estimation survey

Objective

The main objective of GCES, commonly known as Crop Estimation Survey (CES), is to obtain fairly reliable estimates of the average yield of principal food and non-food crops for each State and Union Territory and for such lower administrative units as District, Block, etc. which are of sub-national importance in terms of production, using statistically sound methodology. The estimates of yield rate thus arrived at are adopted for the compilation of official estimates of crop production. Under the CES program, data of yield rate are collected through organizing and conducting a specified number of Crop Cutting Experiments (CCE) at the harvest stage of the crop, by applying a multistage stratified random sampling technique. The elements of the entire process involved in CES are:

- Adopting sampling procedure, allocation and selection of sample villages, the sampling frame being the list of villages. This is done by the designated agency in each State.
- Identification and marking of an experimental plot of a specified size and shape in a selected field on the principal of random sampling.
- Conducting CCE with harvesting and threshing the produce in the experimental plot and recording the weight of the produce.
- In a sub-sample of experiments, further processing of the harvested produced for determining the percentage recovery of dry grain or the marketable produce depending upon the nature of the crop.
- Organizing and processing the data following standardized estimation procedure and corresponding crop areas as weights.

[27] Report of Bihar Crop Survey 1943-44, Sankhya (1954)

[28] Crop Surveys in India, Journal of Indian Society of Agricultural Statistics (1951)

[29] Agriculture Statistics wing of the Indian Council of Agriculture Research was subsequently designated as Indian Agriculture Statistics Research Institute (IASRI)

Organization and scope of CES

CES is a large statistical operation performed in the administrative and geographic spread. Its multi-stage stratified design has uniformity in terms of sampling units such as villages, fields growing experimental crops and has specific requirements of sampling frame. Its organization involves institutions; compatibility and integration with linked statistical activities, particularly generation area statistics (CES design is crop area weighted), availability of sampling frame, human resources and logistics. These features are summarized below:

- There are 29 States administered in the federal structure and the subject of agriculture is the responsibility of the States in federal polity. The respective State institutions such as State Statistical Bureaus, Directorate of Economics & Statistics, Dept. of Agriculture or Land Records are responsible for the planning of the CES, selection of samples, training of the field staff, the quality check of their work and statistical analysis of the data collected. For the primary field work, human resources are drafted from different State institutions/departments related to agriculture and agriculture statistics.
- Within a State, the administrative units are districts, blocks (stratum for CES) and village.
- The system of crop area statistics and in turn the CES is aligned with two broad categories;
    a. The land record states where there is an agency at village level (primary village worker) that maintains the village register of land records (called Khasra Register) containing information on land cover and land use for entire geographical area of the village, land parcels and ownership/holdings, land types and irrigation, season-wise parcel wise crop utilization and cadastral village map. These land records are updated quinquennially and crop use is recorded season-wise as per state calendar. These administrative records are a very useful survey infrastructure and frame for different crop surveys, including the agriculture census.
    b. The majority of States are land record states and crop enumeration is done every year for each village. These records are now also useful for proving the eligibility of crop growers for crop insurance. In land record states, the Timely Reporting Scheme (TRS) is organized and crop area enumeration is undertaken under TRS in a systematic sample of 20 percent of villages on priority and with lesser time lag after the normal sowing period. Thus, the TRS provides an update frame for CES on priority for selection of fields with experimental crop sown. The primary field work of the crop cutting experiments is done by the staff of revenue, agriculture or statistics departments, generally, as part of their normal duties.
    c. In three non-land records states area is estimated through sample surveys (in systematic sample of 20 percent villages every year) under the Establishing Agency for Reporting Area Statistics (EARAS) scheme and for yield, CCEs are planned in a sub-sample of villages selected for the purpose of area enumeration. In EARAS States (West Bengal, Orissa, Kerala, and Meghalaya) the primary work is done exclusively by trained full-time staff of the Bureau of Statistics and Economics.

The required number of CCEs are allocated to districts for desired precision and reliable estimation. The district is called a major or minor district for a crop depending upon the normal area under the crop and CCEs are allocated accordingly. This allows CES to be considered integrated with other survey and census framework with comparability and estimates added at the district onward level.

The number of experiments planned under CES has steadily increased over the years, reflecting the overwhelming response to the approach for wider adoption of sampling techniques of CCEs in the country. The scope of the crop estimation survey over time expanded to meet the challenging needs such as necessity of estimates with higher precision and at lower administrative levels, rising importance of several commercial crops and the data needs on input and crop insurance. Of the total number of experiments planned, around 80 percent of the experiments are on food crops and 20 percent on non-food crops. Kharif (monsoon) season crops account for 58 percent of the experiments and rabi (winter) season crops 42 percent.

Data coverage

Though the primary objective of the crop estimation survey is to provide an estimate of yield rate with a fair degree of precision by adopting the laid-down statistical methodology, a wide range of analysis relating to the agricultural sector and operation can be derived with the help of useful ancillary data collected in this exercise. The opportunity of conducting a survey of such a magnitude is also utilized to obtain data for a wider utility, covering village data, crop data, input data and data on other related classified features. Thus, an exhaustive data profile about the experimental crop and its condition in the field, sowing methods, crop rotation, cropping pattern, crop condition on density, input details such as seeds, fertilizers, pesticides and irrigation are all collected. The information is qualitative as well as quantitative in nature. The ancillary data serve immense utility in undertaking post-stratification analysis to measure the extent and effectiveness of cultivation practices.

Sampling design

The design of the crop estimation survey is one established over a period of time. However, the design and allocation of the sample is periodically reviewed, taking note of changes in cropping pattern, shifts in area and newer crops in the districts. Some of these crops though may not have significance at the state level, but for a particular district these are important. The generic features of CES sampling design and sampling procedure are given below:

- Stratified multi-stage random sampling with Tehsils/Taluks/Revenue Inspector Circle/C.D. Blocks/ Anchals etc. as strata
- Village within a stratum as first stage of unit (fsu) of sampling, survey number/field within each selected village as sampling unit at the second stage and experimental plot of a specified shape and size as the ultimate unit of sampling.
- In some States, the sampling design takes into account the stratification according to input viz. irrigation and seed variety for major crops.
- Experiments for a crop/variety are allotted to districts and then to strata within a district in proportion to the area under the crop/variety in districts/strata within a district. In land record states, villages selected under (TRS) in a stratum for the current year form the sampling frame for the first stage sampling units. Villages are selected through SRSWOR.
- In each selected first stage unit, generally two survey numbers/field growing the experimental crop are selected for conducting crop experiments.

Sampling frame and selection of sampling units

The list of revenue/administrative villages in a stratum serves the frame for the first stage unit. The basic record for the purpose of the frame and for selection of two independent survey numbers is the village register of land record known as "Khasra" register.

If the number of fields growing the experimental crop in a village is less than 200, a fresh list of survey/ sub-survey numbers, i.e. a distinct frame for each experimental crop, is prepared for selection of two survey numbers. If the experimental crop in the survey no./sub survey no. is grown for extension demonstration, prize competition, seed production or for fodder purpose, it is not selected. For location of the survey/sub-survey number, the primary worker is required to consult the village map. There are laid down procedures for substitution of sampling units. However, in cases where the crop is harvested prior to the selection of field or harvested before the date of the experiment or the field is partially harvested affecting the location of experimental crop, substitution of a survey number is not allowed and in such cases, the experiment is treated as lost. In cases where yield is lost on account of poor growth or failure of crop, crop grazed by cattle, damaged by wildlife or affected by pests/diseases/heavy rainfall or inadequate rainfall, the experiment is treated as done and zero yield is reported.

CCE plot size and marking

The size and shape of the experimental plot for various crops in respect of different States are specified. The shapes of the cuts for various crops vary to some extent in different states. But for most of the states and for many of the crops the plots are either square of size 5 meters x 5 meters or rectangle of size 10 meters x 5 meters. In some states (Uttar Pradesh), for most of the crops the plot is equilateral triangle of side 10 meters and in West Bengal, it is circle of radius 1.7145 meters approximately. For some crops, especially fruits and vegetables, it consists of either a specific number of trees or number of rows of plants.

For marking of experimental plots in the field a well laid down procedure is followed and emphasized in field staff training which is periodically conducted. These instructions are detailed under following heads:

- Selection and marking of plots;
- Treatment of border plants;
- Weighing of the produce;
- Driage experiment;
- Crop yield calculation; and
- Treatment of mixed crops.

Estimation of yield

The methodology for estimating average yield of a crop and its standard error of estimates is based on the sampling design of the survey with stratification at various levels. At the stratum level (block/tehsil), the average yield is obtained as a simple arithmetic mean of net plot yields of all experiments. At the district level, average yield of the dry marketable produce per hectare is calculated as a weighted average of the stratum level estimate where weight is taken from the area under crop multiplied by the driage ratio and the conversion factor.

Precision of yield Estimates

The level of precision achieved in estimation of crop yield rates at the State and district levels is monitored through the Standard Error of estimate (SE). The precision required for yield estimation is 3 to 5 percent for major crops and 6 to 8 percent for minor crops at State level. For any given year/crop, the number of crop cutting experiments is decided using the previous year's percentage SE. The States are advised to calculate the SE along with the yield estimate for the crop yield so as to have an optimum number of crop cutting experiments for each crop at all levels. Undue enhancement of the experiments adds to non sampling error to a great extent.

The procedure of yield estimation and the corresponding formulas are given in Annexure-1.

4. Forms for data collection

The State procedure for recording data in various formats is prescribed in the State Revenue Manual. Three specific formats are prescribed for supplying information on various aspects of the conduct of crop-cutting experiments. In each of these formats, provision is made to record the information pertaining to both the experiments. These formats, though broadly identical for all States, vary to some extent in the language, layout, etc. A broad account of the formats and information to be collected in these formats is presented below:

Form No. 1: This form is meant to be filled in by the primary workers at the time of selection of the survey number. After selection, the primary worker has to visit the selected two survey numbers in order to contact the cultivator of the fields and to check the crop and also to collect much relevant information such as eye estimation of expected yield of the crop, sketch a map of the selected fields and also a frame for the selection of survey numbers. Besides the information of selected field, anciliary information on right of cultivation and land revenue paid to the government, total village (fsu) cultivable area and area under experimental crop, type of land and details of crops in the fields during last 3 years, information regarding inputs, irrigation, farming practices, mixed cropping pattern, condition of crop and its density and information regarding rainfall, weeding operation and reasons for damage of crop, if any are also recorded.

Form No. 2: This is the main CCE form to be filled in by the surveyor on the date of experiments. It captures actual observations of CCE such as identification of plot, date of conduct of CCE, weight in kilogram and gram of the green produce as also weight of the straw, input items (such as irrigation, manure, ploughing operation etc.) if any, applied to the crop by the cultivator during the intervening period from the date of selection of field to the date of harvest, number of hired and non-hired workers involved in the harvesting process and their wages, time taken for harvest as also for the post-harvesting operations (i.e. threshing and winnowing), information relating to damage of crop, if any and in case there is wide variation in the eye-estimated yield as reported in the card (along with form no. 1) and the actual yield now obtained, then reasons for such variations are also mentioned.

Form No. 3: This form relates to the collection of information on driage experiments for the crops for which driage experiments are planned; date of harvest and the weight of green produce with and without bag weight of the produce on different dates in the process of driage till the weight becomes constant and final weight of the dried produce.

5. Quality control measures

The survey operation under CES is large in volume and is seasonal. The CCEs are conducted at the harvest stage of the crop in its season. This requires deployment of a large work force. Annually, nearly 50 thousand people from different departments related to statistics, agriculture and rural development are deployed in the CCEs seasons. All the primary workers are thoroughly trained in the crop cutting experiment techniques in each agricultural year/season before they actually take up the field work. Reasonable numbers of experiments are allotted to the primary worker. The latest CES reports that about 85 percent of the staff deputed to CES had attended training so organized.

Supervision of field work is an essential part of any large scale sample survey for ensuring quality of data collected. A three-fold approach is adopted for supervision of crop cutting experiments under GCES. This includes supervision by the departmental staff, by the statistical staff of the SASA and by the staff of the NSSO[30]. A total of about 30 percent of CCEs are supervised by one agency or the other.

[30] The NSSO, a Union Government organization, organizes sample check on CCE at harvest and post-harvest stages in a pre-assigned sample under the scheme for Improvement of Crop Statistics (ICS)

6. Coordination and documentation

The organization and coordination of sample selection, field work and processing of data of the crop estimation survey in the State and to make available its results to the Union Ministry of Agriculture in a time bound program is the responsibility of the State Agriculture Statistics Authority. The NSSO has the overall responsibility of assisting the states for developing suitable techniques for obtaining reliable and timely estimates, providing technical guidance and ensuring adoption of uniform concepts, definitions and procedures of the survey in States. It reviews the design, plans, details of implementation and the results of the surveys, participates in the training camps organized for the State field staff and supervises the primary field work.

The NSSO also organizes documentation of CES following a systematic procedure and brings out a comprehensive publication "Consolidated Results of Crop Estimation Surveys in India" containing all aspects of the survey from planning to processing, including sample size for different crops, aspects of staff deployed, training and supervision, and yield estimates with percentage of SE and post-stratification analysis based on various ancillary data on inputs and cropping practices derived and compiled in the report. The report also highlights the issues that require consideration of States for improving the quality of the survey.

7. Official yield estimates vs GCES yield estimates

The estimate of crop production based on area through field enumeration and yield rate through crop cutting experiments under GCES become available much after the crop is harvested. However, the government needs advance estimates of production for various decisions relating to pricing, distribution, export and import, etc. The Directorate of Economic & Statistics, Ministry of Agriculture (DESMOA) releases advance estimates of crop area and production through periodical forecasts in respect of principal food and non-food crops (food grains, oil seeds, sugarcane, fibers, etc.), which account for nearly 87 percent of agricultural output. Four forecasts are issued, the first in the middle of September, the second in January, the third towards the end of March and the fourth by the end of May. These are based on preliminary eye-estimation, analysis of priority enumeration of area and crop cutting experiments. Forecasts are successively revised with the receipt of complete information through the GCES. A comparison of official yield rates as released by the Ministry of Agriculture based on several inputs and as estimated by the states through GCES indicates that for all those states where the crops are sown as single crop, the official estimates of yield is usually same as obtained through the GCES. In the case of the crops that are sown as mixed, the procedure of apportionment varying from State to State, the two yield estimates usually differ.

8. Concluding observations

The crop estimation survey is amongst the oldest statistical exercises in the world that has consistently grown and strengthened over more than five decades in terms of its methodology, sample size and crop coverage. It is also possibly one of the largest statistical operations of its kind necessitating ad-hoc deployment of more than 50 000 primary surveyors every year to collect important data on crops and the cropping conditions in the different seasons on an annual basis. The CES also recognizes the importance of administrative records at the grassroots level for establishing a scientifically designed survey. There is an institutionalized mechanism of coordination amongst different agencies in the federal structure and the functionaries in the administrative hierarchy. The system of regular training and supervision enhances awareness and sensitivity of people engaged with this activity towards statistical procedures. The expanse of this awareness can be imagined by how many farmers also possibly have come in contact with primary workers engaged with the survey and helping to conduct of crop cutting experiments. The regular documentation of its results and procedural features in the annual report is also one of distinct features of CES operation.

It is however felt that the importance and utility of this important survey operation has still untapped potential. There is much valuable information in the form of ancillary data, that remains less analysed. The CES utility can be further enhanced amongst the planners, policy makers and academicians, if its data base can be organized and disseminated. Since the crop estimation survey uses a standard set of forms year after year, there is scope for using digital technology for capturing data and its analysis. This can enhance not only the timeliness of the results, but also contribute to periodic crop monitoring and an early warning system for the farm sector.

It may not be exaggeration to rate CES as one of good practices of the statistical endeavors followed in the world, contributing to official statistics, consistently, year after year, with enhanced utility and trust.

* * * * * * * * * * * * * *

Annexure-1

Estimation Procedure of Crop Yield in CES

Notations:

- X_{ijk} The plot yield (net) in gms/plot of the k[th] plot in the j[th] village in the i[th] stratum
- n_{ij} No of experiments analyzed in the j[th] village of i[th] stratum,
- m_i No. of villages in which experiments are analyzed in the i[th] stratum.
- n_i Number of experiments analyzed in the i[th] stratum
- S The number of strata in a district
- a_i The area (net) of the crop in the i[th] stratum
- x_{ij} The sample arithmetic mean of the green yield of the i[th] stratum,
- $\bar{x}$ The district average yield of the dry marketable produce
- d The driage ratio
- f The conversion factor for converting the green yield per plot into the yield of dry marketable produce per hectare.

Formulae:

i) Stratum level average of the green yield is given by

$$\overline{x_{ij}} = \frac{1}{n_i}\sum_{j=1}^{m_i}\sum_{k=1}^{n_{ij}} X_{ijk}$$

ii) District level average yield of the dry marketable produce per hectare is given by

$$\bar{x} = d.f.\frac{\sum_{i=1}^{s} a_i\ x_{ij}}{\sum_{i=1}^{s} a_i}$$

iii) Sampling variance of the mean $\bar{x}$ is obtained as

$$V(\bar{x}) = \frac{d^2 .f^2\left[W\sum_{i=1}^{s}\frac{a_i^2}{n_i} + (B-W)\sum_{i=1}^{s}\frac{a_i^2\ \sum_{j=1}^{m_i} n_{ij}^2}{\lambda_i\ n_i^2}\right]}{\left[\sum_{i=1}^{s} a_i\right]^2}$$

Where $$\lambda_1 = \frac{n_i^2 - \sum_{j=1}^{m_i} n_{ij}^2}{n_i - (m_i - 1)}$$

$$B = \frac{\sum_{i=1}^{s}\left[\sum_{j=1}^{m_i}\frac{\left(\left(\sum_{k=1}^{n_{ij}} x_{ijk}\right)^2\right)}{n_{ij}} - \frac{\left(\sum_{j=1}^{m_i}\sum_{k=1}^{n_{ij}} x_{ijk}\right)^2}{n_i}\right]}{\sum_{i=1}^{s}(m_i - 1)}$$

is mean square between villages and

$$W = \frac{\sum_{i=1}^{s}\left[\sum_{j=1}^{m_i}\ \sum_{k=1}^{n_{ij}} x_{ijk}{}^2 - \sum_{j=1}^{mi}\frac{\left(\sum_{k=1}^{n_{ij}} x_{ijk}\right)^2}{n_{ij}}\right]}{\sum_{i=1}^{s}(n_i - m_i)}$$

is mean square within villages.

iv) The percentage standard error is given by

$$\% \text{ SE } (\overline{x}) = \frac{\sqrt{V(\bar{x})}}{\bar{x}} \text{ x } 100$$

Notes:

(i) In case the crop sown is pure, the net yield is the same as the actual yield obtained from the plot.

(ii) If the crop is sown in mixture, then the net yield is obtained by dividing the actual yield by the eye estimate of the proportion of area occupied by the concerned crop as per the primary worker at time of crop cutting experiments.

(iii) the area under the crop in a stratum is the sum of the area under the pure crop and the apportioned area under the crop from all mixed crops having the crop as a component, the apportionment being done at the field level on the basis of eye estimation at the time of area enumeration in some states and at district level in others on the basis of conventional ratio.

An assessment of pre- and within-season remotely sensed variables for forecasting corn and soybean yields in the United States

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An assessment of pre- and within-season remotely sensed variables for forecasting corn and soybean yields in the United States

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ABSTRACT

Four timely and broadly available remotely sensed datasets were assessed for inclusion into county-level corn and soybean yield forecasting efforts focused on the Corn Belt region of the central United States (US). Those datasets were the (1) Normalized Difference Vegetation Index (NDVI) as derived from the Terra satellite's Moderate Resolution Imaging Spectroradiometer (MODIS), (2) daytime and (3) nighttime land surface temperature (LST) as derived from Aqua satellite's MODIS, and (4) precipitation from the National Weather Service (NWS) Nexrad-based gridded data product. The originating MODIS data utilized were the globally produced 8-day, clear sky composited science products (MOD09Q1 and MYD11A2), while the US-wide NWS data were manipulated to mesh with the MODIS imagery both spatially and temporally by regridding and summing the otherwise daily measurements. The crop growing seasons of 2006–2011 were analyzed with each year bounded by 32 8-day periods from mid-February through late October. Land cover classifications known as the Cropland Data Layer as produced annually by the National Agricultural Statistics Service (NASS) were used to isolate the input dataset pixels as to corn and soybeans for each of the corresponding years. The relevant pixels were then averaged by crop and time period to produce a county-level estimate of NDVI, the LSTs, and precipitation. They in turn were related to official annual NASS county level yield statistics. For the Corn Belt region as a whole, both corn and soybean yields were found to be positively correlated with NDVI in the middle of the summer and negatively correlated to daytime LST at that same time. Nighttime LST and precipitation showed no correlations to yield, regardless of the time prior or during the growing season. There was also slight suggestion of low NDVI and high daytime LST in the spring being positively related to final yields, again for both crops. Taking only NDVI and daytime LST as inputs from the 2006–2011 dataset, regression tree-based models were built and county-level, within-sample coefficients of determination (R^2) of 0.93 were found for both crops. Limiting the models by systematically removing late season data showed the model performance to remain strong even at mid-season and still viable even earlier. Finally, the derived models were used to predict out-of-sample for the 2012 season, which ended up having an anomalous drought. Yet, the county-level results compared reasonably well against official statistics with $R^2 = 0.77$ for corn and 0.71 for soybeans. The root-mean-square errors were 1.26 and 0.42 metric tons per hectare, respectively.

1. Introduction

1.1. Crop yield statistics

Accurate and timely estimation of local and regional crop yield statistics is important for a variety of reasons. On the macroeconomics level they allow societies to understand the food and fiber supply which in turn helps the demand side plan for and better utilize the finite crop resources. In the most developed countries this is manifested through futures contract markets which are most efficient and fair for price discovery when transparent and current statistics are available. Local, direct to consumer markets work similarly in that statistics help both parties understand the value of the crop. From a management standpoint, yield information gives a farmer a baseline of what is typically expected to be produced and thus can be used to best establish risk, insurance premiums or the value of input costs. Established yield information also highlights the impact to crops from natural events such as severe weather or changing climatic conditions. Likewise, regional yield statistics help quantify how strategies such as planting methodologies, irrigation, fertilizer and pesticide use are playing out in aggregation and can identify regions that are chronically underperforming, or have a "yield gap."

The United States Department of Agriculture (USDA) spends considerable effort in determining United States (US) crop yields in service to the agricultural community. The statistical arm of the USDA, the National Agricultural Statistics Service (NASS), conducts two large panel surveys (USDA, 2012) that are annually ongoing throughout the growing season (USDA, 2010) to establish state- and national-level yield estimates. The first is known as the Agricultural Yield Survey

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The research agenda of the Global Strategy to Improve Agricultural and Rural Statistics foresees the potential of alternative methods and opportunities such as advances in satellite-based technology for improving crop estimation and monitoring.

Many institutions in Asia and the Pacific region are using remotely sensed data in conjunction with conventional statistical methodologies to estimate the crop area and to forecast yields. The applications of these methods have achieved diverse degree of success, depending upon the nature of agriculture and/or access to advanced satellite imagery.

The Expert Meeting on Crop Monitoring for Improved Food Security provided an occasion for over 50 experts from Asia and other regions to deliberate on best practices and methodological issues, and to identify challenges for future research work.

This publication summarizes the outcomes of the deliberations in the meeting and presents a collection of technical papers on the subject. A comparative study of the methods presented in the book will be useful to the countries which are planning to integrate these new technologies in their statistical programme.

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