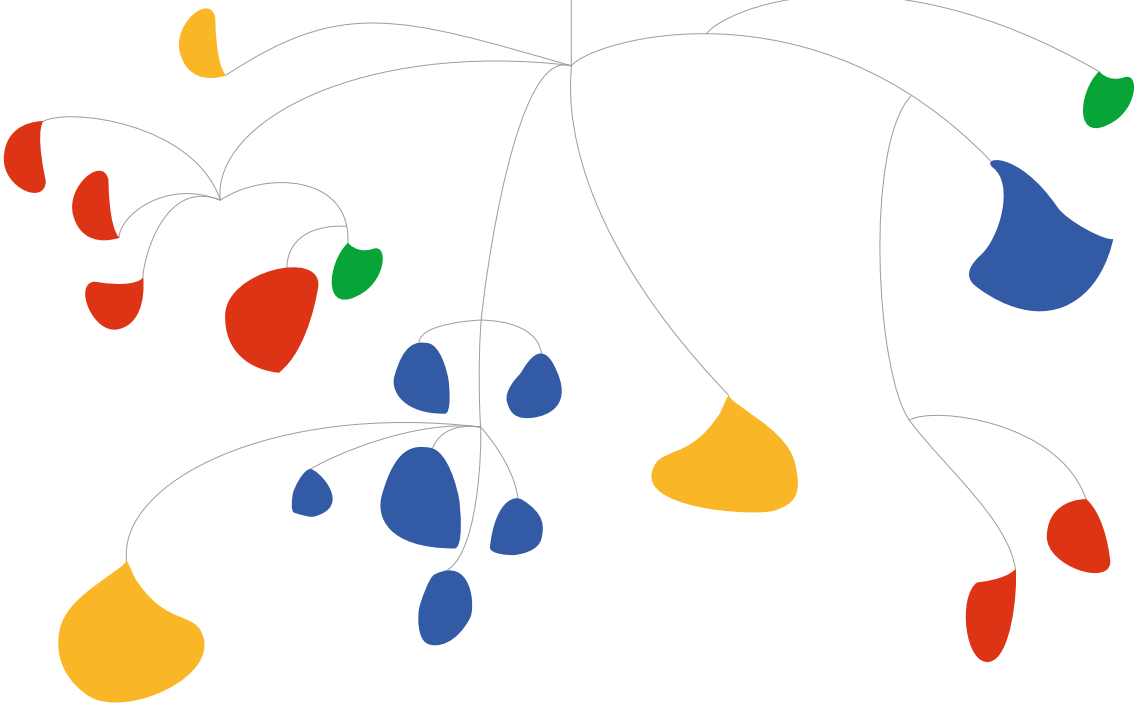
Food and Agriculture Organization of the United Nations

Crop Yield Forecasting:
Methodological and Institutional Aspects

Current practices from selected countries
(Belgium, China, Morocco, South Africa, USA)
with a focus on AMIS crops
(maize, rice, soybeans and wheat)

AMIS
Agricultural Market Information System



CROP YIELD FORECASTING: Methodological and Institutional Aspects

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Comments and suggestions are welcome and may be sent to: info@gsars.org

It is envisaged to publish a second version of this document, which will take into account further country experiences and any feedback received.

Purpose

Pietro Gennari[1] and François Fonteneau[2]

Forecasting crop production (and crop yield in particular) has been a constant concern since the beginning of the history of agriculture. Forecasting techniques have evolved, as has agriculture itself and the specifications of the forecasts needed. Those who use forecast data are always seeking greater accuracy, granularity, comparability, and timeliness. Those who produce the data or contribute to their production always operate under financial and technical constraints. Obtaining timely knowledge presents a very real challenge.

Today, the human, institutional, technical and financial infrastructure behind crop forecasts and yield forecasts in particular can be incredibly complex. This publication provides insights into such complex data infrastructures at the country level. It highlights good practices and prospects for the future. The countries examined herein were selected to reflect a variety of agricultural systems, financial and technical capacities and solutions and methodologies implemented.

The objective of this publication is to complement the literature available – which details existing individual methodologies – by describing the functioning of complex institutional set-ups. This could eventually help improve national systems which still struggle to produce forecasts of the quality needed for policy design and market operation.

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Preface

Jacques Delincé[1]

The work on crop biomass production began several years ago, with the development of detailed bio-physical models (de Wit 1965). The first evolution in the sector occurred in the 1980s, with the shift towards simpler statistical yield models. With the introduction of new space research programs (USDA-AgRISTARS - Wilson et al., 1981; ISRO-CAPE - Navalgund et al., 1991), new opportunities emerged for predicting international trade shocks such as the 1972 Soviet Union wheat imports, which severely disrupted crop commodity prices and availability. Today, crop yield/production forecasts are widely used at world, national, regional and field levels, but they differ significantly in terms of objectives, methodologies, data needs, timeliness, costs and reliability (Rembold et al. 2013). This Preface seeks to introduce the criteria that a national statistical office should consider before embarking upon crop yield forecast activities.

Purpose of the forecast

The purpose of crop yield and production forecast activities should be the reduction of the risks associated with local or national food systems. Adopting the model proposed by Pinstrup-Anderson and Wilson (2011), the food system envisages various components (natural resources and inputs; primary/secondary production; transport, storage and exchange; consumption; health and nutrition) and agents (policymakers, producers, inputs sellers, output buyers, farm advisors, researchers). Risk reduction should contribute to improved outcomes in terms of the environment (better flows of and access to natural capital), socioeconomic aspects (increased wealth, income, employment, and economic growth), and health and nutrition (reduced diseases, morbidity, and mortality rates).

The chosen scale in terms of space and time will affect the interests of the actors of the food system. Targeting the farmer level, "prescriptive farming" (Schumpeter 2014) as applied by Monsanto, Du Pont Pioneer, and Land O'lakes in the USA aims to perform in-field yields modeling to improve management techniques and boost actual yield. In India, the Mahalanobis National Crop Forecasts Centre (MNCFC) issues crop production forecasts for the country's eight major crops to serve policy needs.

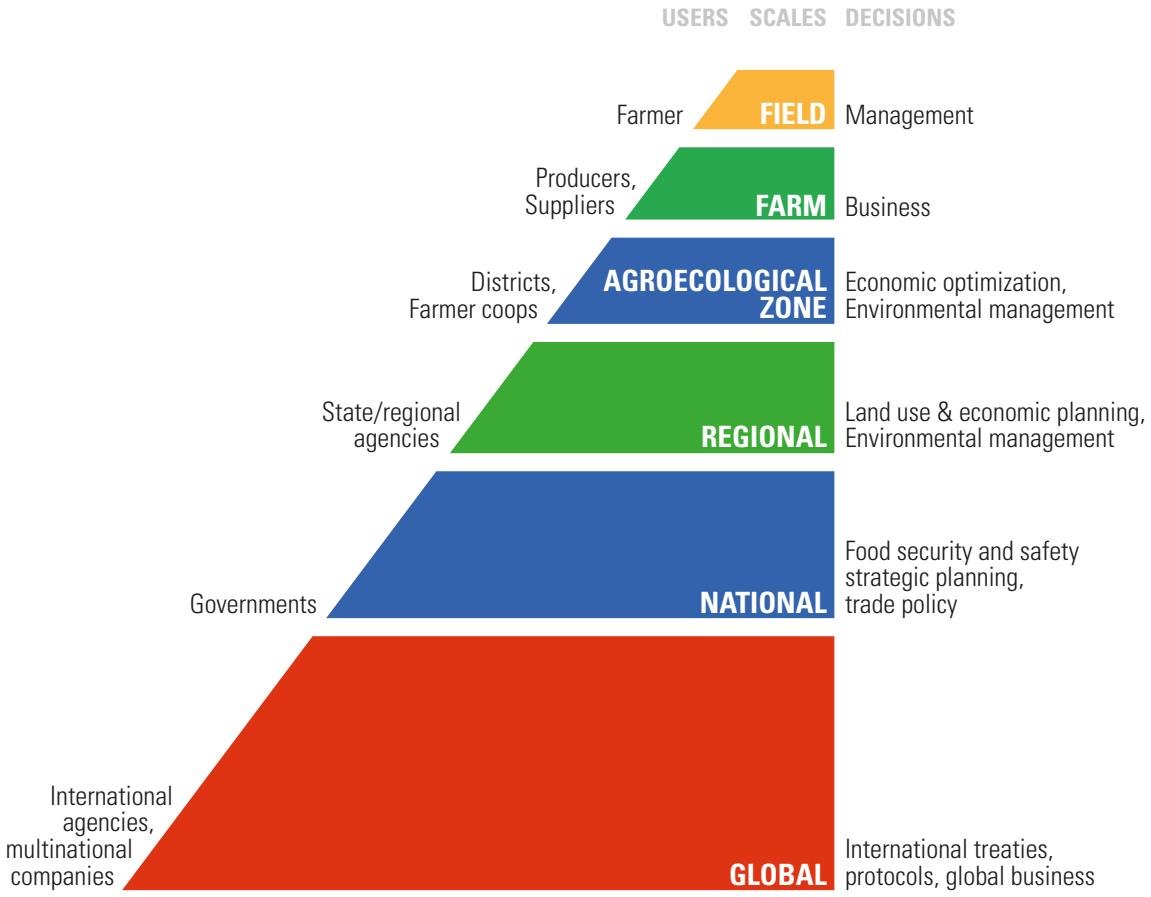
The same applies to the time dimension. The Agricultural Model Inter-comparison and Improvement Project (AGMIP – see Rosenzweig et al. 2013) seeks to improve agricultural models in light of the medium- and long-term effects of climate change on crop yields. An outcome of the 2011 G20 summit, the GEOGLAM project (www.geoglam-crop-monitor.

[1] Global Strategy to Improve Agricultural and Rural Statistics, FAO Statistics Division.

org) monitors current year conditions and contributes national crop production forecasts (for wheat, soybeans, corn, and rice) computed by 30 national partners to the AMIS Outlooks on a monthly basis[2].

An additional variable consists in the choice between forecasting yield or production. While farmers may derive the yield by dividing production by crop extension, institutional forecasts obtain the production forecast by multiplying expected yield by the crop area. However, current-year crop areas are costly to obtain and rarely available at the time needed. The recent development of Crop Data Layers (CDL) is an efficient solution in regions with large field sizes; in addition, the African 20m monthly land cover maps announced by ESA (derived from Sentinel 2) could be a free-of-charge operational solution for the African continent (54 countries).

The figure below, extracted from documentation distributed at the Seattle NextGen meeting (Jones et al. 2014), summarizes the interactions between actors, components and scales of the food system and should assist identification of the forecast's purpose.



[2] http://www.amis-outlook.org/fileadmin/user_upload/amis/docs/AMIS_brochure.

Evaluation criteria

The evaluation criteria should be based on the forecasting system's capacity to induce changes in the relevant agents' behaviour, resulting from their perception of risk reduction.

Wilson et al. (1981) identified the ideal properties of models: reliability, objectivity, consistency with scientific knowledge, adequacy to scales, minimum cost and simplicity. Today, these can be reframed in the following terms.

Timeliness is essential. While an advance of one month with respect to the harvest date is usually chosen for food security monitoring, economic actors such as traders not only expect several annual outlooks; for their purposes, the strict observance of the announced publication dates is of primary importance, since issuance of this information generally influences international commodity markets.

The model's simplicity and structure (Donatelli et al. 2010) and the minimum data sets required (MDS, Basso et al. 2013) affect the forecasting system's costs (relating to human resources, data purchase, hardware and software). Open-source model frameworks (such as DSSAT and BIOMA) should be favoured because – in addition to enabling gains in time in system development – they will provide solutions whose robustness is guaranteed by the large community of users.

Due to climate change, extreme weather events are becoming more frequent, and historical data poorly represent the growing conditions obtaining after the year 2000. The sensitivity to extreme events has thus become an issue of high priority, as "normal" years are less in need of reliable forecasts. If models are not updated, old models risk lacking relevance.

As in any statistical process, forecasts should show low root mean square errors (below 5 or 10 percent) and no systematic errors. Usually, this can be verified only after several years of implementation.

Current approaches

While the scientific approach originally led to the development of crop-specific mechanistic models that examined in detail plant physiology and its interaction with the air and soil environments, none of these models could be the core of operational crop yield forecast models. Currently, two modeling approaches compose this core: statistical models and process-based models:

Statistical models are usually regression models (simple or multiple, linear or non-linear, static or dynamic) that link the variables of interest (i.e. the yields) to the predictors known for the current season. Based on parameters estimated from historical data, they are used to infer the most probable current-year outcome. The predictors are chosen from the meteorology (pluviometry, temperature, solar radiation) and/or the remote sensing (vegetation indices, LAI, soil moisture) domains. Statistical crop models are simple and entail low costs; several authors have claimed to achieve over 75 percent of variance explanation. The models' main drawback is that they have the smallest prediction interval around the average of the

reference dataset, whereas actors of the food system are mostly interested in abnormal years. In addition, these models cannot be extrapolated in time or space

Process-based models mimic mechanistic models by replacing the theoretical relations with empirical functions. The level of approximation, the choice of processes modeled and the datasets retained led to the current diversity of models, whose benchmaking remains a challenge. Most models require information on crop management (planting dates, phenology, variety), nutrient availability (soil parameters, fertilization), water availability (soil moisture, evapotranspiration) and energy received (solar radiation). Models are mostly deterministic, although some recent developments refer to stochastic approaches (Chipanshi et al. 2015). Today, most models make use of remote sensing information (in particular, to derive the crop phenology) and reference validated datasets are becoming available for meteorological data (NCAR 2014), soil information (FAO et al. 2009), satellite imagery (USGS 2015) and land cover mapping (Basso et al. 2014).

Finally, it must be recalled that most yield models perform crop yield assessments, but very few of them report on the biomass production of pasture land (although grasslands occupy 70 percent of agricultural land). Among the main reasons for this are the complexity introduced by multi-species aspects, competition with scrubs and trees, and grazing or periodical cuttings. Although most of the solutions proposed refer to the regression of pasture biomass with remote sensing vegetation indices (Donald 2010), some process-based models have also been devised (Tauber 2012).

Ongoing evolution

Several evolutions of crop yield models are currently taking place, following international initiatives such as the IPCC, AGMIP, NEXTGEN, CIMSANS and GEOSHARE. Academia, public administrations and the private industry are joining forces to boost the models' integration process and to foster interaction, knowledge sharing and model comparison.

Great efforts are currently ongoing to secure open access to validated datasets (both historical and real-time) on soil information, meteorological data, remote sensing indicators and land cover mapping. Considering the amount of data now available on the Internet (there exist approximately 300 data sources for meteorological information alone), the main problem faced by today's crop modelers lies more in choosing which data sources to use rather than how to access them. New remote sensing products are appearing, providing new data (such as the SMAP for soil moisture) and innovative working environments (see NOAA's Data Alliance with Amazon WS, Google CP, IBM, Microsoft and OCC).

Considering the food industry's priorities, it can be expected that models will evolve from pure biomass production forecasts to the estimation of associated externalities. Under pressure from citizens, crop water use (in competition with drinking water under shortage scenarios), nitrogen/phosphorus soil pollution and greenhouse gas emission will be new required outputs. In the context of the rise in global obesity, the nutrient content of crops will also become a priority, as commercial strategies are pursued. In addition, as the peri-urban production of vegetables is a component of food security resilience, new crops (consisting

essentially of internationally traded crop commodities) will be added to the actual crop list. The main uncertainty will be the extent to which technology sharing will be a two-way (public/private) or one-way process due to patenting and business constraints.

Another evolution will be the move from forecasting potential yield to forecasting actual yield. While most models may be viable under limited water or nutrient availability, too few are capable of integrating the aspects linked to weeds, pests, diseases, pollutants, or adaptation. Due to climate change, new weeds and pathogens will appear; contemporary water management techniques will have to adapt to water scarcity; higher temperatures and CO2 concentrations will occur; and molecular genetics will exacerbate the ageing of current modeling options. Considering the unprecedented weather variability, extreme events of heat, drought and rain will have to become modeling priorities.

Based on the above, it can be expected that the future of crop yield modeling will entail multi-disciplinary inter-institutional frameworks consisting of modular open-source code running on validated free access reference datasets. Crop yield models (code and data) should become public goods that the private sector and the public administration would integrate into their field, regional, national, and global crop forecast framework. In addition, "soft" solutions will appear as smartphone apps, to facilitate the use of crop models by extension advisers or even farmers.

Organizational aspects

As mentioned above, crop yield forecasting is a complex multi-disciplinary exercise. Its implementation within a national statistical system will require a multi-year establishment period and collaboration among services, as well as financial investments. Considering that competences in crop management, plant physiology, meteorology, soil science, remote sensing and information technology are required, new structures must be envisaged, integrating staff from different services with budgets for software (database, GIS, image analysis, web services) and hardware (workstations, disk storage, Internet services); data and model access (even open-source requires training); and subcontracting (heavy data processing by the private sector).

At continental level, the needs can be evaluated by examining well-established cases: the Indian Mahalanobis National Crop Forecasting Centre relies on a team comprising 20 staff members and an annual budget of USD 1.5 million. The European MARS AGRI4CAST project is composed of a team of 23 persons, with an annual budget of USD 1.5 million. In both cases, extended collaboration with external actors enables free access to additional resources.

For national systems, it is possible to implement a smaller team and a lower budget, but as the level of detail required will generally be higher, project costs and team size will probably not decrease drastically (indeed, CNT-CGMS in Morocco relies on a team of 23 staff members).

Although the mentioned investments are lower than the cost of an agriculture survey, it should be noted that these projects always rely on close collaborations with national space centres or research programs, thus limiting the investment to the marginal additional expenses linked to project implementation.

Remaining challenges

The main unknown factor concerning the future of crops production is related to the effects of climate change – in particular, the extent and rapidity of these changes. As mentioned above, one of the challenges consists in the real-time estimation of crops; however, this will be even more significant if crop optimal location, management techniques or diseases progress at a greater speed. In the last 15 years in China, double or triple seasons cropping has moved 100 km to the north, enabling a dramatic increase in rice and wheat production due to changes in crop areas. Likewise, models based on past observations will become less relevant, especially when synthetic biology takes over the selection of varieties, which is currently based on genetics. Also, it will be necessary to identify solutions to for the effects of climate variability and extreme events on the output of models. Even if forecasts may withstand greater uncertainty than estimation methods, limits exist beyond which results will no longer be useful.

Another challenge derives from the role of the private sector in developing the models. The quest for profit maximization by ascertaining consumer preferences, the best production places (as a function of soil quality, radiation and pluviometry) and future market evolution (evolution of products' cross-elasticities as a function of GDP levels), will be only partially satisfactory. The public sector will have to finance the developments corresponding to the applications at national level, whereas the private sector is likely to boost the research at local level, aiming to perform field-level simulations and comparing the results of various types of management practice. The reconciliation and bi-directionality of information flows will certainly require particular attention.

Acronyms

ACRU	Agricultural Catchments Research Unit (South Africa)
AgMIP	Agricultural Model Improvement and Inter-comparison Project (South Africa)
AFS	Area Frame Sampling
AMSS/CAS	Academy of Mathematics and System Science, Chinese Academy of Sciences
APR	*Association Pédologique Régionale* (Belgium)
APSIM	Agricultural Production Systems SIMulator
ARC	Agricultural Research Council (South Africa)
ASB	Agricultural Statistics Board (United States)
AURELHY	*Analyse Utilisant le RElief pour les besoins de l'HYdrométéorolgie* (Morocco)
AVHRR	Advanced Very High Resolution Radiometer
AYS	Agricultural Yield Survey
BAM	Bank Al Maghrib (Morocco)
B-CGMS	Belgian Crop Growth Monitoring System
BELSPO	Belgian Science Policy Office
CAERSS	Cropland Acreage Estimation by Using Remote Sensing and Sample Survey
CAS	Chinese Academy of Sciences
CATI	Computer-Assisted Telephone Interviewing
CDL	Cropland Data Layer
CEC	Crop Estimates Committee (South Africa)
CELC	Crop Estimation Liaison Committee
CGMS	Crop Growth Monitoring System
CGMS-MAROC	Crop Growth Monitoring System – Morocco
CGSM	Crop Growth Simulation Model
CHARMS	CHina Agriculture Remote sensing Monitoring System
CIPF	*Centre Indépendant de Promotion Fourragère* (Belgium)
CLO	*Centrum voor Landbouwkundig Onderzoek – Gent* (Belgium)
CMA	China Meteorological Administration
COLA	Center for Ocean-Land-Atmosphere Studies (South Africa)
COY	Corn Objective Yield (United States)
CPC	Climate Prediction Center (United States)
CPC	Communist Party of China (China)
CRA-W	*Centre Wallon de Recherches Agronomiques* (Belgium)
CRID	Coarse Resolution Imagery Database (South Africa)
CRM	*Centre de Recherches sur le Maïs* (Belgium)
CRTS	Royal Centre for Remote Sensing (Morocco)
CSI	Climate Suitability Index
CST	CGMS Statistical Toolbox
CV	Coefficient of Variation

DAFF	Department of Agriculture, Forestry and Fishery (South Africa)
DBMS	DataBase Management System
DEM	Digital Elevation Model
DG-AGRI	Directorate-General for Agriculture
DMN	National Department of Meteorology (Morocco)
DMP	Dry Matter Productivity
DPO	Dry Bean Producers' Organisation (South Africa)
DSS	Department of Strategy and Statistics of the Ministry of Agriculture (Morocco)
DUL	Drained Upper Limit
DVS	Crop development stage
ECMWF	European Centre for Medium-Range Weather Forecasts
EDR	Electronic Data Reporting
EMU	Elementary Mapping Unit
ENSO	El Niño Southern Oscillation (United States)
ESA	European Space Agency
EU	European Union
EU MARS Unit	European Union Monitoring Agricultural ResourceS Unit (EU)
EUROSTAT	European Union Statistical Office
EVI	Enhanced Vegetation Index
EWEM	Early Warning and Environmental Monitoring Program
FAS	Foreign Agricultural Service (United States)
FAM	Frequency Accumulation Means
FEWS	Famine Early Warning System
FIWAP	*Filiere Wallonne de la Pomme de Terre* (Belgium)
FUSAGx	*Faculté Universitaire des Sciences Agronomiques de Gembloux* (Belgium)
GCI	Grain Crops Institute (South Africa)
GDARD	Gauteng Department of Agriculture and Rural Development (South Africa)
GEOGLAM	Group on Earth Observations Global Agricultural Monitoring
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographic Information System
GLAM	Global Agricultural Monitoring (United States)
GMFS	Global Monitoring for Food Security
GPS	Global Positioning System
GRS	Ground Random Sampling
GVI	Greenness Vegetation Index
IGES	Institute of Global Environment and Society Institute for Soil Climate and Water (South Africa)
ISCW	Institute for Soil Climate and Water (South Africa)
HCP	High Commission for Planning of the Directorate of Statistics (Morocco)
IACS	Integrated Administration and Control System (Belgium)
IAV	*Institut Agronomique et Vétérinaire Hassan II* (Morocco)
IGN	*Institut Geographique National* (Belgium)
INRA	National Institute for Agricultural Research (Morocco)

IRM	*Institut Royal Météorologique de Belgique*
JAS	June Crops/Stocks Survey (United States)
JAWF	Joint Agricultural Weather Facility (United States)
JECAM	GEO Joint Experiment for Crop Assessment and Monitoring
JRC-MARS	MARS Unit of the Joint Research Center
LAI	Leaf Area Index
LDA	Limpopo Department of Agriculture (South Africa)
LL	Lower Limit
LSWI	Land Surface Water Index
MARS Project	Monitoring of Agriculture with Remote Sensing
MAS	March Crops/Stocks Survey (United States)
MCYFS	MARS Crop Yield Forecast System
MoA	Ministry of Agriculture
MODIS	Moderate resolution Imaging Spectroradiometer
MoF	Ministry of Finance
MSG	Meteosat Seconde Generation (Belgium)
MPPS	Multivariate Probability Proportional to Size
MPZ	Major Production Zone
MRU	Monitoring and Reporting Unit
NAFU	National African Farmers Union
NAMC	National Agricultural Marketing Council (South Africa)
NASS	National Agricultural Statistics Service (United States)
NBS	National Bureau of Statistics (China)
NCSC	National Crop Estimates Consortium (South Africa)
NDRC	National Development and Reform Commission
NDVI	Normalized Difference Vegetation Index
NIS	National Institute of Statistics
NMSs	National Meteorological Services (Morocco)
NOAA	National Oceanic and Atmospheric Administration
NOAA-AVHRR	National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer
NPP	Net Primary Production
NSRCP	National Statistics and Remote Sensing System of Crop Production
NUTS	Nomenclature of territorial units for statistics (from the French *Nomenclature des unités territoriales statistiques*)
OYS	Objective Yield Survey
PAMOS	Provincial Agrometeorological Operation and Service System
PASG	Percentage of Average Seasonal Greenness
PDA	Personal Digital Assistant
PDA	Provincial Department of Agriculture
PECAD	Production Estimates and Crop Assessment Division (United States)
PICES	Producer Independent Crop Estimates Survey
PPS	Probability Proportional to Size
PRF	Protein Research Foundation
PSU	Primary Sampling Unit
RADI/CAS	Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences

RMSE	Root Mean Square Error
RS	Remote Sensing
RSAC	Remote Sensing Application Center (China)
RSS	Remote Sensing Section (United States)
RVI	Ratio Vegetation Index
SACOTA	South African Cereals and Oilseeds Trade Association
SAFEX	South African Future Exchange
SAG	State Administration of Grain
SAGIS	South African Grain Information System
SAM	Southern Annular Mode
SANSA	South African National Space Agency
SANSOR	South African National Seed Organisation
SAR	Synthetic Aperture Radar
SAT	Saturation
SAWS	South African Weather Service
SCM	Systematic Clustering Means
SDVI	Standardized Difference Vegetation Index
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SGI	Small Grain Institute (South Africa)
SMME	Small, Medium, and Micro-sized Enterprise
SMU	Soil Mapping Unit
SPI	Standardized Precipitation Index
SSM	Stratified Sampling Method
SST	Sea Surface Temperature
STRM	Shuttle Radar Topography Mission
TAFSS	telephone or field interview area and yield survey
TU	Terrain Unit
UAV	Unmanned Aerial Vehicle
UCL	*Université catholique de Louvain*
UKZN	University of KwaZulu-Natal
UNIMI	University of Milan
USDA	US Department of Agriculture (United States)
USDA/NASS	United States Department of Agriculture's National Agricultural Statistics Service (Morocco)
VCI	Vegetation Condition Index
VITO	Flemish Institute for Research and Technology (from the Flemish *Vlaamse Instelling voor Technologisch Onderzoek*)
WASDE	World Agricultural Supply and Demand Estimates
WOFOST	World Food Studies

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Crop Yield Forecasting in Belgium

Michele Bernardi[1]

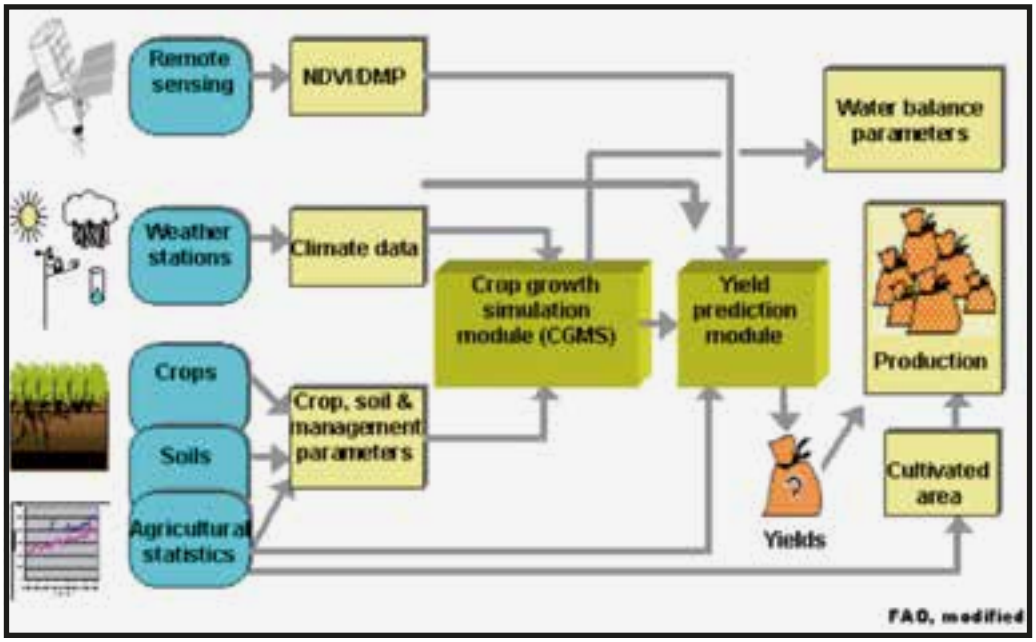
1. Crop yield forecast data for Belgium

1.1. Brief description

In Belgium, the National Institute of Statistics (NIS[2]) does not provide crop yield forecasts. However, the Belgian Crop Growth Monitoring System (B-CGMS[3]) provides – on a voluntary basis – reliable, timely and objective forecasts of crop yields for six main crops in Belgium, at national and sub-national levels (14 agricultural regions and 26 circumscriptions). The crop yield forecasts are produced by combining the results of a Crop Growth Simulation Model (CGSM), a trend function linked to the long-term increases obtainable through technological improvements, and the information provided by the 1-km^2 resolution imagery of the remote sensing systems NOAA-AVHRR (National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer[4]) and/or SPOT-VEGETATION[5] (see Figure 1.1. on the following page, which provides a schematic representation of the process followed by the B-CGMS in producing crop yield forecasts.

[1] Independent Consultant.
[2] National Institute of Statistics: http://statbel.fgov.be/en/statistics/figures/.
[3] B-CGMS: http://b-cgms.cra.wallonie.be/.
[4] NOAA-AVHRR: http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html.
[5] SPOT-VEGETATION: http://www.spot-vegetation.com/.

FIGURE 1.1
B-CGMS descriptive flowchart



Source: Tychon et al., 2000.

In the B-CGMS, crop yield forecasts are computed by combining the Normalized Difference Vegetation Index (NDVI) and the Dry Matter Productivity (DMP) obtained through remote sensing, the results of a process based model, and a trend function.

Although the B-CGMS is an adapted and improved version of the Crop Growth Monitoring System (CGMS)[6] implemented at EU level, the B-CGMS is operated in Belgium in a fully independent manner, and its various databases and input data come from different sources (Tychon et al., 2000). The system's main improvements will be discussed in Section 2.2.1. below.

1.2. Inventory of forecasts available, by source

1.2.1. National official sources

Since 1942, the NIS is the official provider of crop yield estimates in Belgium. The methodology for estimating crop yields was modified in 1995 and revised in 2014 (De Baets, 1996). The information is based on a survey, conducted each year in May, of 1,500 selected farms, which represent 75 percent of farmers. Provisional results are available one month after the survey,

[6] The CGMS is the core of the MARS Crop Yield Forecast System (MCYFS), which is currently used in forecasting activities in Europe within the AGRI4CAST action. http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/Crop-Growth-Monitoring-System-CGMS.

and the final results are released after 7 months, generally after the month of December. The results are provided at national, regional, provincial and agricultural region levels. The combination of crop yield and crop area estimates enables crop production to be estimated.

1.2.2. Other non-official national sources

An unofficial source of crop yield forecasts at national level is the B-CGMS, which releases detailed information from April to September. The B-CGMS began in 1998, within the framework of a 2-year bilateral project between Belgium and China, funded by the Belgian Science Policy Office (BELSPO[7]), and coordinated by the ULg-University of Liège[8] (Arlon Campus Environment, the former Fondation Universitaire Luxembourgeoise), CRA-W[9] (Centre Wallon de Recherches Agronomiques – Walloon Agricultural Research Centre), VITO[10] (Flemish Institute for Research and Technology) and the IRM[11] (Institut Royal Météorologique de Belgique). The B-CGMS uses as input data the official yield statistics supplied by the NIS. Other agronomic data are supplied by CRA-W (Dpt. Productions et Filières), IRBAB[12] (Institut Royal Belge pour l'Amélioration de la Betterave), FIWAP[13] (Filiere Wallonne de la Pomme de Terre), and the CIPF[14] (Centre Indépendant de Promotion Fourragère).

Another source of crop yield forecasts for Belgium is the European Union's Monitoring Agricultural Resources (EU-MARS[15]) Unit, which provides timely forecasts for the EU's agriculture and food policies, pursuant to a mandate conferred by the EU's Directorate-General for Agriculture (DG-AGRI). The DG-AGRI is responsible for the implementation and control of the EU's various agricultural policies. To manage these policies, the DG-AGRI requires detailed information on the planted area, the crop yield and production. Information on land use, land use changes and yields is routinely collected by various national statistical services, which then convey this information to the EU's statistical office, EUROSTAT. The collection and compilation of these agricultural statistics is a time-consuming and laborious process. In exceptional cases, these statistics are available some months after the season has ended; however, as a rule, one or even two years elapse before this information is available in the EUROSTAT databases. Consequently, during this stage, these statistics are of limited use for the timely evaluation of the various policies, and more timely and accurate information is needed. The original MARS (Monitoring of Agriculture with Remote Sensing) project began in 1988, to generate monthly information on land use, land use changes, and exceptional growing conditions such as water stress and expected yields. This information was to be provided for various crops for all EU Member States. To achieve this objective, the MARS project used field surveys, high- and low-resolution satellite data and a crop growth simulation model. To estimate the expected yields, a crop growth simulation model was combined with a detailed soil map, parameters for the various crops and spatial crop information to create

7 BELSPO: https://www.belspo.be/
8 ULg: http://www.facsc.ulg.ac.be/cms/c_636656/en/arlon-campus-environnement-home
9 CRA-W: www.cra.wallonie.be
10 VITO: https://vito.be/en
11 IRM: http://www.meteo.be/meteo/view/en/65239-Home.html
12 IRBAB: http://www.irbab-kbivb.be/
13 FIWAP: www.fiwap.be
14 COPF: http://www.cipf.be/fr/accueil.html
15 EU-MARS Unit: http://mars.jrc.ec.europa.eu/mars/About-us

the CGMS. The CGMS uses daily meteorological observations to estimate the crop status (i.e. water stress, biomass production, etc.) during the growing season, and the crop yield at the end of the season.

1.2.3. Other regional or global sources

The Université catholique de Louvain (UCL[16]) is part of the GEO Joint Experiment for Crop Assessment and Monitoring (JECAM)[17] on crop identification and crop area estimate. The JECAM has the following objectives:

- Cropped Land: Develop a method to support crop area estimation on field for a NUTS level 3 resolution (the minimum mapping unit), and establish the mapping frequency (2 maps per year – 1 for winter wheat mapping, 1 for maize mapping).
- Crop Condition/Stress: Improve the estimates of biophysical variables retrieval for crop growth monitoring. Develop a methodology for the estimation of maize and winter wheat Leaf Area Index (LAI[18]) from optical radars and the Synthetic Aperture Radar (SAR[19]).
- Soil Moisture: Analyse the SAR data's sensitivity to soil surface parameters (surface roughness and soil moisture) over agricultural fields, at various polarizations. Investigate the options for scaling down the evapotranspiration data that is available from the Meteosat Seconde Generation (MSG[20]) satellite every 30 minutes.

1.3. Release calendars: punctuality and timeliness

The NIS provides crop yield estimates[21] on the basis of a survey conducted in two phases: one preliminary phase in August, and one final phase in December.

Every three months, from April to September, crop yield forecasts produced by the B-CGMS for main crops at agricultural region level are published in an agrometeorological bulletin[22], which is released 10 days after the end of the month and made available on the B-CGMS website. The B-CGMS performs data processing at 10-day (dekad) temporal intervals.

The monthly EU-MARS bulletin[23] releases, from January to December, provide yield forecasts for the main cereals at national level for the 28 EU Member States, Turkey, Ukraine, the Russian Federation, Belarus and the Maghreb countries.

[16] Université catholique de Louvain: http://www.uclouvain.be/en-276351.html.
[17] JECAM Belgium/France: http://www.jecam.org/?/project-reports/belgium-france.
[18] LAI is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area (LAI = leaf area/ground area, m2/m2).
[19] SAR: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/SAR_missions.
[20] EUMETSAT-Meteosat: http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Meteosat/index.html.
[21] NIS crop estimates: http://statbel.fgov.be/fr/statistiques/chiffres/economie/agriculture/exploitations/#.VK0ahHte83Y.
[22] B-CGMS Bulletin: http://b-cgms.cra.wallonie.be/download-bulletins-fr/.
[23] EU-MARS bulletin: ftp://mars.jrc.ec.europa.eu/Bulletin/Europe/.

1.4. How do these different forecasts compare? Purpose, coverage, scale and harmonization issues, and accuracy

Until 1994, the official estimates coordinated by the NIS were based on a subjective method, with the crop yield estimates being computed by experts. Pursuant to criticism from EUROSTAT, a reform of the system was initiated in 1992 and a new method was developed and implemented in 1995. A description of the new methodology is presented in Section 3.1 below.

The B-CGMS provides crop yield forecasts at the same administrative levels as those of the NIS; as historical crop statistics, the data are as coherent as those provided by the NIS, and are used for the statistical model. A detailed description of the crop yield forecasting methodology performed by the B-CGMS is provided in Section 2.2. below. Considering that the B-CGMS and EU-CGMS outputs are released in end-June, they are very close to the estimates produced by the NIS. Table 1.1 below compares the crop yield forecasts at national level for the main crops, as released by the three different systems.

TABLE 1.1.
Crop yield forecast (t/ha) at national level for the 2013 cropping season as released by NIS, B-CGMS and EU-CGMS, and based on their respective methodologies

System	Yield (t/ha)			
	Winter wheat	Winter barley	Maize	Fodder Maize
NIS	9.25	8.51	11.33	45.06
B-CGMS	8.97	8.33	NA	46.09
EU-CGMS	8.70	8.40	11.77	

Date of release:
NIS = December 2013
B-CGMS = 28 June 2013
EU-CGMS = 17 June 2013

2. Belgium's national sources: methodology and practices

2.1. Description of the official yield forecasting methodology

In Belgium, the official source provides crop yield estimates, and not crop yield forecasts. The method established by the NIS in 1995 seeks to be more objective that the one applied previously – indeed, the new method is based on measurements of the quantities harvested within selected farms, while the old method was based on expert judgments within agricultural circumscriptions, and thus sometimes led to underestimations. The NIS estimates crop production by combining the results of two surveys: one on crop acreage and another one on yield. The survey on crop acreage is conducted in the spring, through an agricultural and horticultural census conducted around 15 May. The yield survey is conducted in two phases: a preliminary stage in August and a final stage in December. The final

estimate is computed by interviewing a sample of 1,500 farms. This farm cover represents approximately 5 to 10 percent of total crop acreage and approximately 2.5 percent of the total number of farms. The combination of the two surveys provides a preliminary estimate of crop production by 1 October of the current year, and a final estimate by 1 October of the following year (De Baets, 1996).

2.2. Description of the non-official yield forecasting methodology

2.2.1. The B-CGMS' overall methodology

An unofficial source of crop yield forecasts is the B-CGMS. The project proposed a comparative analysis of Belgium and China's Heilongjiang province to compare the Chinese and Belgian CGMSs. In particular, the project sought to introduce the remote sensing approach into the Chinese system and to improve the remote sensing interface of the Belgian system; an additional goal was to adapt and improve both systems. The B-CGMS is an independent implementation of the European Crop Yield Forecasting System (MCYFS) implemented by the MARS Unit of the Joint Research Center (JRC-MARS[24]). A brief description of the MCYFS is given in Annex B1.2. below.

The B-CGMS is independent of the European MCYFS model, and is adjusted to Belgium's local conditions. This adjustment required the original MCYFS to be modified, to take into account i.e. pedo-climatological databases, the crop parameters and the working scale (Table 1.2). Indeed, as more detailed information became available at Belgian level (e.g. weather stations network, soil map), the basic grid size (of 50 x 50 km in the CGMS) was modified as described in Section 1.1 above.

Table 1.2 highlights the main differences between the original European model and the B-CGMS.

[24] JRC-MARS: http://mars.jrc.ec.europa.eu/mars/About-us/The-MARS-Unit.

TABLE 1.2.
Differences between the EU-CGMS and the B-CGMS

	EU-CGMS	B-CGMS
Spatial divisions	Outputs only at level of 2 NUTS (Nomenclature of Statistical Territorial Units) – regions (Flanders, Wallonia)	Outputs also at level of agricultural region (14) and circumscription (26)
Grid	50 x 50 km	3 different levels: 1 x 1 km, 5 x 5 km and 10 x 10 km
Soil data	European soil geographical database (1 : 1,000,000)	1 : 500,000 and Aardwerk database of soil profiles
Suitability soil / crop	Based on soil types	Based on additional use of land use data (IACS[25] [26])
Soil mapping unit	Consists of one or more soil types	Contains only one soil type
EMU[27] = NUTS Ç Soil mapping unit Ç Grid	1 EMU consists of more than one simulation unit	1 EMU corresponds to one simulation unit

Source: Tychon et al., 2000.

Like the CGMS, the B-CGMS system can be subdivided into three operational levels:

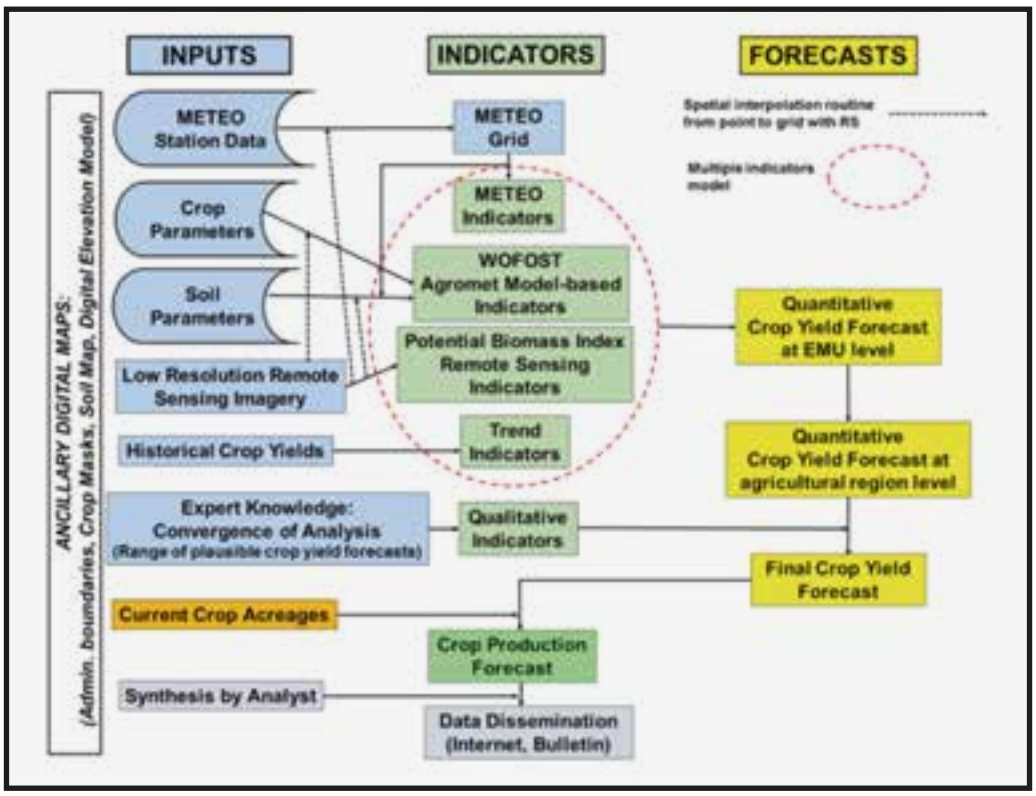
- **Level I: Spatial interpolation of real-time meteorological data.** At this stage, raw data from weather stations are spatially interpolated on a regular grid, with the use of remote sensing imagery.
- **Level II:**
  - Crop growth simulation. This is the core of the B-CGMS. It is based on a deterministic process-based model of crop growth (the University of Wageningen's World Food Studies, or WOFOST[28]).
  - Crop yield forecasting. This is an integration of the biomass estimations obtained from the crop growth model, from the information provided by the 1-km2 resolution imagery of the NOAA-AVHRR[29] or SPOT-VEGETATION[30] remote sensing systems, and from a trend function linked with the long-term crop yield increases made possible by technological advances.
- **Level III:** Aggregation in standard administrative units at various spatial scales.

Schematically, the B-CGMS' operation is based on Figure 1.2 below:

- **Inputs data** (i.e. meteorological, agricultural, soil, remotely sensed imagery, historical crop statistics);
- **Derived indicators** (i.e. meteorological, crop growth model, potential biomass index, trend function); and
- **Yield forecasts**, produced at EMU and at agricultural region level through a multiple indicators model.

[25] IACS: Integrated Administration and Control System of the Ministry of Agriculture
[26] IACS: http://ec.europa.eu/agriculture/direct-support/iacs/index_en.htm
[27] Acronym for Elementary Mapping Unit
[28] WOFOST: http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/World-Food-Studies-WOFOST
[29] NOAA-AVHRR: http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html
[30] SPOT-VEGETATION: http://www.spot-vegetation.com/

FIGURE 1.2.
Synthetic flowchart of the B-CGMS



Source: Tychon et al., 2000.

In the B-CGMS, a series of input data (meteorological, agricultural, and soil data, remotely sensed imagery, and historical crop statistics) are used to compute a set of derived indicators. These are, in turn, used to produce crop yield forecasts at EMU, regional, and national levels.

As mentioned above, the system's core engine is the WOFOST crop growth model, which simulates crop growth and its development to obtain the yield value. Various crop growth variables are simulated, such as the biomass, the weight of stock organs, and the LAI in potential and real water conditions from emergence to harvest. WOFOST presupposes that crop production is the result of the interaction of three factors:

- Meteorological data;
- Cropping parameters (phenological and physiological);
- Soil data, in particular their water characteristics, to calculate water balance and determine the water available for crop growth.

The database is the B-CGMS' main component, and contains all inputs and outputs. Most of the database's tables form a permanent part of the database, but some tables are temporal (i.e. created and deleted by the executable program). Ancillary Geographic Information System (GIS) maps are part of the database and may focus the following aspects: administrative boundaries (national, regional, district), crop distribution (i.e. crop mask), soil, and DEM (Digital Elevation Model). The B-CGMS uses the following variables or input parameters (see

Table B1.1., Annex B1.3. for a complete list):

- Meteorological (6 variables, updated daily);
- Phenological (6 parameters, updated annually);
- Physiological (47 parameters, permanent data); and
- Pedological (12 parameters, permanent data).

In addition, the database contains historical and current remote sensing imagery, provided by VITO, at a 1-km^2 resolution of the remote sensing systems NOAA-AVHRR and/or SPOT-VEGETATION; these may be used for the spatial interpolation of point values to grid, and to derive certain important variables from the NDVI[31], such as the DMP[32]. The list of input data, the frequency of updating and the supplier are shown in Table 1.3 below.

TABLE 1.3.
Input data, frequency of updating and supplier

Input data	Frequency of updating	Supplier
GIS maps	Permanent data	IGN[33]
Historical time series meteorological data	Permanent data	IRM
Current meteorological data	Daily	IRM
Historical time series phenological data	Permanent data	CRA-W
Phenological data	Annual	CRA-W
Physiological data	Permanent data	CRA-W
Pedological data	Permanent data	CRA-W
Historical time series crop yield data	Permanent data	NIS
Historical time series Remote Sensing imagery	Permanent data	VITO
Current Remote Sensing imagery	Daily	VITO
Agricultural parcel data	Monthly	IACS

Source: Tychon et al., 2000.

2.2.2. GIS data

The following GIS data are part of the B-CGMS database:

- Vector coverage with administrative boundaries;
- Vector coverage or grid with the network of meteorological stations;
- Vector coverage or grid of the altitude;
- Vector coverage of soil map;
- Vector coverage of the spatial distribution of crops.

2.2.3. Meteorological data

The meteorological database is the first important component of the system, and consists of three different datasets: metadata, the historical time series and current data (Figure

31 The NDVI is a measurement of plant growth (vigour), vegetation cover, and biomass production from multispectral satellite data. The NDVI is calculated from the red and near-infrared (NIR) spectral channels as: NDVI=NIR–red/NIR+red.
32 The Dry Matter Productivity (kgDM/ha/day) is proportional to the (better-known) Net Primary Productivity (gC/m²/day).
33 IGN (Institut Geographique National): http://www.ngi.be/

B1.8., Annex B1.2). The historical time series and current meteorological data are provided by the IRM, and are then spatially interpolated to obtain a regular grid of points as inputs to the crop growth model at Level II, or to measure the deviation of a specific variable from the long-term average. The choice of spatial resolution is a compromise between the precision of yield, the processing time and the working scale. Three resolution grids are retained: 10 km^2, 5 km^2 and 1 km^2. For a 10 km^2-grid, 370 cells are required to cover the entire country (Figure B1.2, Annex B1.1). The metadata identifies each meteorological station by its geographical coordinates:

- Latitude (to decimal degrees);
- Longitude (to decimal degrees); and
- Altitude (m).

The IRM's historical database contains time series of 23 years of daily meteorological data for 150 stations, and is used as a basis for quantifying the annual deviations from long-term averages. The following data are included:

- Station number;
- Calendar day [dd-mm-yyyy];
- Daily sunshine duration(2) [hours];
- Daily global radiation at surface(1) [KJ/m^2/jour];
- Minimum air temperature(4) [°C];
- Maximum air temperature(4) [°C];
- Daily mean vapour pressure [hPa];
- Daily mean wind speed at a height of 10 m [m/s];
- Daily precipitation [mm/day];
- Daily mean of total cloud cover(3) [oktas];
- Calculated reference evapotranspiration from the above [mm/day].

To derive the global radiation, the following four methods are available, in order of preferability (N.B. the numbers indicated as superscripts in the above list of data refer to these four methods):

1. Measurement of global radiation;
2. Deriving global radiation from the daily sunshine duration and the Ångström formula[34];
3. Deriving global radiation from the daily mean of the total cloud cover and the Supit formula[35];
4. Deriving global radiation from the temperature and the Hargreaves formula[36];

One of the three data sources (measured, sunshine, cloud cover) should be available;

[34] The Ångström formula is R_g=R_a*(A_a+B_a*(n/L)), where R_g is the global radiation, R_a is the Angot radiation, n represents the bright sunshine hours per day, L is the astronomical day length, and A_a and B_a are the regression coefficients that depend on the geographical location. The Angot radiation is the amount of extraterrestrial radiation; for its calculation, see Supit et al. (1994).

[35] The Supit formula is $R_g = R_a * A_s\left(\sqrt{T_{max} - T_{min}}\right) + B_s\sqrt{\left(1 - \frac{CC}{8}\right)}) + C_s$, where T_{min}, T_{max} are respectively the minimum and the maximum daily temperature, CC is the cloud cover in octets, and A_s, B_s, C_s are the regression coefficients. The regression coefficients depend on the geographical location.

[36] The Hargreaves formula is $R_g = R_a * A_h * \sqrt{(T_{max} - T_{min})} + B_h$, where A_h and B_h are the regression coefficients that depend on the geographical location.

otherwise, the temperature is used. Therefore, the minimum basic set consists of temperature, vapour pressure, wind speed and rainfall. When these data are not available, it may be possible to estimate them from other data. For example, formulas exist to convert wind speed from one height to another. Likewise, there are formulas to derive the vapour pressure from the dew point temperature, the relative humidity or the wet-bulb temperature. Meteorological data for the current agricultural season are provided daily by the IRM and are then spatially interpolated, to obtain grid surfaces for the following five variables:

- Temperature (daily maximum, daily minimum);
- Precipitation (daily total);
- Wind speed (daily average);
- Water vapour pressure;
- Global radiation (daily total) or a proxy (sunshine duration, cloud cover).

The sixth variable, the reference evapotranspiration[37], is calculated from the above:

- Potential evaporation of water surface (mm/day);
- Potential evaporation of wet bare soil (mm/day);
- Potential evapotranspiration of a crop canopy (mm/day).

2.2.4. Agricultural data

The agricultural database is the system's second important component. For each crop and variety, it includes six phenological[38] and 47 physiological[39] parameters that are inputs for the agronomic model (a complete list is available in Table B1.1, Annex B1.3.). Furthermore, the parameters listed immediately below are included for each crop and variety, for each agricultural region, and for the last 20 years, based on observations collected for approximately 21,000 agronomic field trials:

- Sowing date (ddd);
- Emergence date (ddd);
- Flowering date (ddd);
- Maturity date (ddd); and
- Grain yield (kg/ha/year).

Most physiological parameters are functions of the crop development stage (DVS). Examples are phenology (sowing-flowering-maturity), daily assimilation (photosynthesis), respiration, dry matter partitioning, decay rate of storage organs, leaf area dynamics (growth and decay), root growth, water use and the initialization of dry matter accumulation process (growth). The crop parameters are provided by the various national agronomic institutions, such as:

- Centrum voor Landbouwkundig Onderzoek – Gent (CLO);

[37] The reference evapotranspiration can generally be described by the FAO-Penman-Montheith equation (Allen et *al.*, 1998): $\mathrm{ET}_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 * u_2)}$, where ET_0 is the reference evapotranspiration, R_n is the net radiation at the crop surface, G is the soil heat flux density, T is the mean daily air temperature at a height of 2 m, e_s is the saturation vapour pressure, e_a is the actual vapour pressure, e_s - e_a is the saturation vapour pressure deficit, Δ is the slope of the vapour pressure curve, and γ is the psychrometric constant.

[38] Phenological data includes the length of crop development stages, and planting and harvest dates.

[39] Physiological data includes rooting depth, and the required sum of temperatures between emergence and maturity of a specific crop.

- CIPF;
- CRA-W;
- Centre de Recherches sur le Maïs (CRM);
- IRBAB; and
- Faculté Universitaire des Sciences Agronomiques de Gembloux (FUSAGx).

The database includes time series of historical crop yield (agricultural statistics[40]) for the last 30 years, which are provided by the NIS and to be used in calculating the trend function during the phase of calibration and validation of the crop forecasting system.

2.2.5. Agricultural parcel data

The EU-MARS crop forecasting system has established a regional inventory process at European level, to assess acreage using images from high-resolution remote sensing. In Belgium, the practice applied to compute crop acreage estimates was replaced by the Integrated Administration and Control System (IACS[41]), to collect information on the land use for each crop. The IACS is responsible for encoding the declarations provided by farmers, so that agricultural parcels of the entire territory are available in digital format, and accurate information on each farmer's land use is recorded. In this system, each agricultural parcel of the entire country is available in a numerical format. This vectorial GIS file contains the boundaries and crop type for almost all agricultural parcels (approximately 620,000) of the entire country, and is updated every year. This source of information is another unique feature of the B-CGMS system, compared to the EU-MARS system. Following the establishment of an extraction process, the project possesses the entire dataset of agricultural parcels at a 1-km^2 resolution grid. Each cell is characterized by the number of parcels and the respective acreage for each crop. This information is used either as an input to the WOFOST model, to determine crop distribution over the country (land use and crop mask), or to estimate agricultural production.

2.2.6. Pedological data

The pedological database is the B-CGMS' third main component. Its parameters are used in the soil water balance to determine the content of available water for crop growth (a complete list is available in Table B1.1, Annex B1.3). The data are extracted by soil profile for each mapping unit, and are permanent. A new soil mapping unit (SMU) was determined by combining the Tavernier and Marchal map (1974) and the map of the pedological zones (see Figure B1.3., Annex B1.1). For each SMU, a representative soil profile for soils under cultivation was established, together with its associated physical and chemical data; most of this information was retrieved from the soil profile AARDEWERK database (Van Orshoven & Vandenbroucke 1993). The 226 subdivisions obtained were called APRs (*Associations Pédologiques Régionales*) and the polygons composing the APR were taken as SMUs, the basic mapping unit to describe soil properties. The module for calculating the water balance

[40] Agricultural statistics include the planted area and the yield of different crops during the last 15 years for each circumscription and agricultural region.

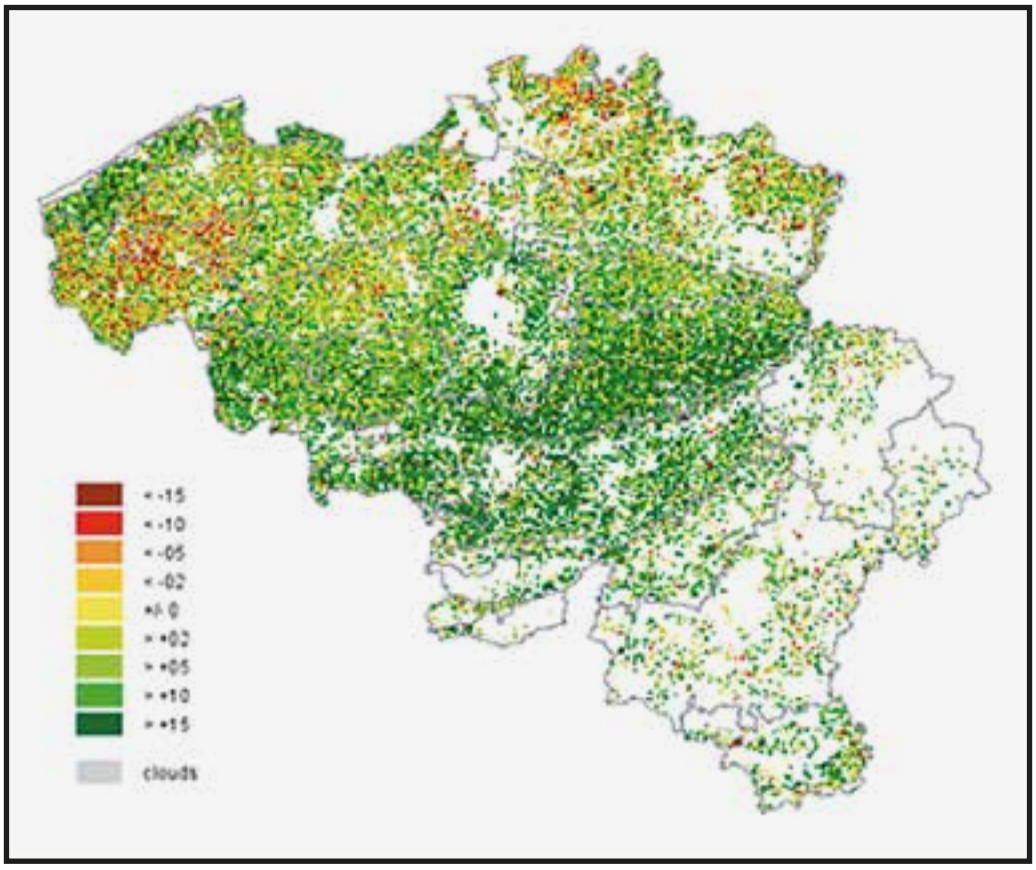
[41] IACS: http://ec.europa.eu/agriculture/direct-support/iacs/index_en.htm.

requires information on the specific soil characteristics and their spatial distribution, on the basis of simulation units. Each soil type is identified by a geo-referenced cartographic unit (the geographic database) associated to two groups of factors (the analytical database): (i) the Rooting Depth; and (ii) the Soil Physical Group, which provides the soil's hydrodynamic properties. The parameters characterizing the soil's water retention and hydraulic conductivity do not exist in Belgium's soil maps, or in the 1988 AARDEWERK database (Van Orshoven & Vandenbroucke 1993); however, they are necessary for the crop growth model. Therefore, the pedotransfer functions are used; these equations estimate the unknown parameters from the information that is available in Belgium's soil database.

2.2.7. Remote sensing imagery data

The B-CGMS uses the 1-km² spatial resolution and 10-day temporal resolution imagery of NOAA-AVHRR and SPOT-VEGETATION to improve its crop yield forecasts. The database includes historical satellite imagery for the last 15 years, and current imagery obtained every ten days. From the satellite imagery, the NDVI (Figure 1.3 below) is processed and the DMP is calculated.

FIGURE 1.3.
The Normalized Difference Vegetation Index



Source: Tychon et al., 2000.

An example of the NDVI processed from the satellite imagery in the B-CGMS database.

2.2.8. The Crop Growth Simulation Model

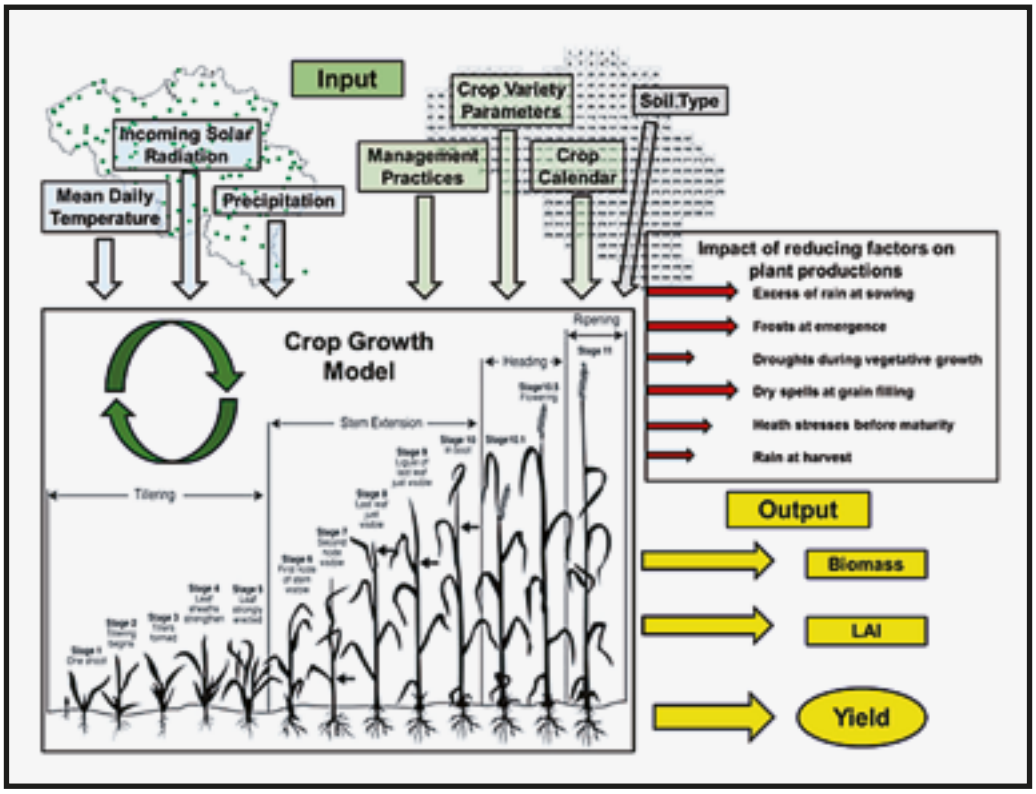
WOFOST is a semi-deterministic process-based model of physiological processes that simulates crop growth at a daily time interval. A simplified scheme of the WOFOST model's input and output variables is shown in Figure 1.4. The following input variables (a complete list of which is available in Table B1.1., Annex B1.3) are used:

- 46 crop parameters, including 34 single parameters and 12 multiple parameter tables (dynamic parameters that are a function of the DVS or of temperature);
- Variety (regional cultivars, some parameters of which are modified);
- Crop calendar;
- Start of season (emergence or sowing); and
- End of season (maturity or harvest).

The simulation runs from sowing to maturity and is based on the crop's response to weather and soil moisture conditions. The following variables are calculated:

- Phenology (sowing-flowering-maturity);
- Light interception;
- Assimilation (Photosynthesis);
- Respiration;
- Assimilate partitioning;
- Leaf area dynamics (growth and decay):
- Evapotranspiration; and
- Soil/water balance.

FIGURE 1.4.
Crop Growth Model simplified scheme



Source: modified from Baruth 2013.

The WOFOST model uses a set of input variables – including 46 crop parameters, the crop calendar, and regional cultivars some parameters of which have been modified – to produce the following output variables: 1) crop development stage; 2) crop total biomass and yield under potential and water-limited conditions; 3) crop leaf area index under potential and water-limited conditions; and 4) soil moisture, transpiration.

The plant's physiological age is defined by its development stage, each of which is characterized by the formation or appearance of different organs. The most important phenological change occurs from the vegetative to the reproductive stage, which determines a large redirection of dry matter allocation towards the plant organs. Because many physiological and morphological processes change once the phenological stage begins, its accurate quantification is essential for any crop growth simulation model. For many annual crops, the development stage can be conveniently expressed as a dimensionless variable, having a value of 0 at seedling emergence, of 1 at flowering and of 2 at maturity. To mark the beginning of the growing season, either the sowing or emergence date may be chosen; however, if the sowing date is selected, the WOFOST model determines the emergence date and thus the beginning of the crop growth simulation. The crop emergence can be defined as a function of the sum of effective daily temperatures since the sowing date. Emergence takes place when the sum of effective daily temperatures reaches the emergence threshold temperature. This threshold temperature is crop-specific and should be provided by the user. The daily effective temperature depends on the base temperature, below which no phenological processes

take place, and the maximum daily temperature, beyond which phenological activity no longer increases.

The output variables are the following:

- Crop development stage;
- Crop total biomass and yield under potential & water-limited conditions;
- Crop LAI under potential & water-limited conditions; and
- Soil moisture and transpiration.

In recent years, the FROST variable was added to take into account the risk of frost for winter crops (wheat and barley). The FROST variable is calculated by weather variables and represents the number of frost days between 1 December and 31 March of a given year. A day is considered to have frost when the minimum temperature is below 0°C.

2.2.9. Crop yield forecast

The WOFOST model provides the following indicators, at 10-day (dekad) intervals:

- Biomass and yield of storage organs in potential conditions and under real precipitations;
- Estimated soil water reserve (the difference between current and past dekad or past month);
- Development state of crop cycle during the current dekad.

The final crop yield forecast (**Y**) is obtained by combining the outputs of the function on technological trends with those of the agrometeorological model and of the biomass indicator, as given by remotely sensed data. The model's equation is:

$$\mathbf{Y = a + f_1(Trend) + f_2(CGMS) + f_3(RS) + \xi}$$

where

$\mathbf{Y}$	= the forecasted yield
$\mathbf{f_1(t)}$	= the function linked to the technological trend
$\mathbf{f_2(CGMS)}$	= the function linked to the meteorological conditions (agrometeorological model)
$\mathbf{f_3(RS)}$	= the function linked to the biomass indicator as given by remotely sensed data
$\boldsymbol{\xi}$	= the random component (error).

For each circumscription or agricultural region, a linear[42] or quadratic[43] function of the technological trend is calculated or adjusted by the least square method, over periods of 15 and 30 years.

[42] Linear function: $y = a + b_1 t$.
[43] Quadratic function: $y = a + b_1 t + b_2 t^2$.

Remotely sensed data contributes to the crop yield forecast by computing the daily increases DW in dry matter (DM) biomass, by means of the following equation:

$$\mathbf{DW = S_{par} \times fAPAR \times e(T)\ [kgDM/ha/day],}$$

where

Spar = the incoming Photosynthetic Active Radiation in J/ha/day (± 50% of the Sun's short-wave spectrum)
fAPAR = the fraction absorbed by living vegetation
e(T) = the conversion efficiency in kgDM/J, a function of the daily mean temperature **T**

Ten forecast models have been used, applying the same technological trend based on periods of 15 or 30 years, but with different indicators as outputs of the agrometeorological model and of the biomass, based on remotely sensed data:

Model I: Trend
Model II: Trend + POT_BIO
Model III: Trend + POT_STO
Model IV: Trend + WL_BIO
Model V: Trend + WL_STO
Model VI: Trend + RS
Model VII: Trend + POT_BIO + RS
Model VII: Trend + POT_STO + RS
Model VIII: Trend + POT_STO + RS
Model IX: Trend + WL_BIO + RS
Model X: Trend + WL_STO + RS
where

Trend = the technological trend over 15 or 30 years

POT_BIO = the potential yield of biomass as an output of the agrometeorological model
POT_STO = the potential yield of storage organs as an output of the agrometeorological model
WL_BIO = the biomass yield over real hydrological conditions, as an output of the agrometeorological model
WL_STO = the storage organs yield over real hydrological conditions, as an output of the agrometeorological model.
RS = the biomass indicator based on remotely sensed data.

The results of these processes are introduced into a statistical model (multiple regression), and the weight of each component is obtained by a statistical fitting process for each dekad. The quality of the prediction of the three different yield or biomass indicators may change considerably during the growing season. Therefore, throughout the growing period, it is

sought to minimize the prediction error by optimizing the weights given to the three system components (i.e. the difference between the yield values observed by the NIS and those that were predicted).

This large amount of data, consisting of 11,989 simulation units for each dekad and each crop, is then aggregated. This is achieved through a specific module that aggregates all the output data from the agrometeorological model for all municipalities, circumscriptions and agricultural regions (see Figure B1.7, Annex B1.2). Each of these components is considered according to the cultural period for which the root mean square error representing the prediction error is lowest.

The accuracy and stability of different models, as well as the reliability of the forecasts, are evaluated from the coefficient of determination R^2, the root mean square error (RMSE) of the estimation error, the coefficient of variation (CV) and the root mean square error representing the prediction error. These parameters are calculated for each model for each of the six crops, at the levels of agricultural circumscriptions and agricultural regions. The forecast error estimate is an essential quality of a crop forecasting system. For example, the JRC considers that the forecast error is low when it is lower than 3% and no higher than 6% (Genovese & Bettio 2004). The CGMS forecasts the yields of major crops in Europe with an error between 3 and 5% (and of 8.6% for wheat). The models that integrate the potential biomass as derived from remote sensing imagery have performed best.

2.3. Relevant practices for data collection

Two types of data are used in the system: data that is permanent over time, and data that evolves over time. Prior to the operational phase, there is an initial phase for collecting data that is permanent over time, i.e. phenological data, physiological data, soil data, GIS digital maps (administrative boundaries, soil map, DEMs, etc.), meteorological data (historical time series), and historical crop statistics. The cost of data updating and its impact on precision are detailed in Table 1.4 below. The cost refers to the entire data collection process (i.e. human and data processing time) and may be incurred either by the data provider or by the data recipient; it can also be provided in kind, in the case of team partners. Although data are now processed in digital format, the formats used by the provider and the recipient often differ. Thus, a great proportion of time is spent in data reformatting, as the data must be adapted to the input requirements of the specific application being used (e.g. WOFOST), and the databases must adhere to these requirements.

TABLE 1.4.
Frequency of data updating and cost estimates

Input data	Frequency of updating	Cost of updating (€)	Impact on precision
GIS maps	Permanent data	15,000	Average
Historical time series meteorological data	Permanent data	15,000	Low
Current meteorological data	Daily	10,000/year	Low
Historical time series phenological data	Permanent data	10,000	Average
Phenological data	Annual	10,000/year	Low
Physiological data	Permanent data	10,000	Low
Pedological data	Permanent data	10,000	Low
Historical time series crop yield data	Permanent data	10,000	Average
Historical time series (Remote Sensing imagery)	Permanent data	Free	Variable
Current Remote Sensing imagery	Daily	20,000/year	Variable
Agricultural parcel data	Monthly	15,000/year	High

Source: Oger et al., 2000.

2.4. Practices for data sharing and analysis, harmonization and integration

As shown above, data collection can be a very costly and time-consuming process; their standardization could provide a partial solution, at least. Although data harmonization is recognized as an important way to reduce the cost of data sharing, it is actually a very complex matter. For example, in meteorology, it is considered a priority, because standardized procedures must be used if observations made at the same time in different locations around the world are to be compared. However, the data provided by the national meteorological service are not necessarily in the format used by crop simulation models such as WOFOST. In this case, specific procedures must be developed to transform the original format to that used by WOFOST. Although data are now processed in digital format, the formats used by the provider and by the recipient are often different. If the data are provided in hard copy, very tedious and time-consuming manual data-entry procedures must be used to record the data in the database. Data harmonization is also fundamental when using the same administrative boundaries. Therefore, data collection and processing must refer to the same boundaries for which the crop yield prediction is to be made.

The B-CGMS crop yield forecasts are obtained by calibrating all available indicators, regardless of their different natures (meteorological, remote sensing, trend or growth models indicators), against official yields. Although this method is simple, it is not user-friendly and is rather difficult to implement. Moreover, as most of the different steps are executed manually, the risk of error can be significant.

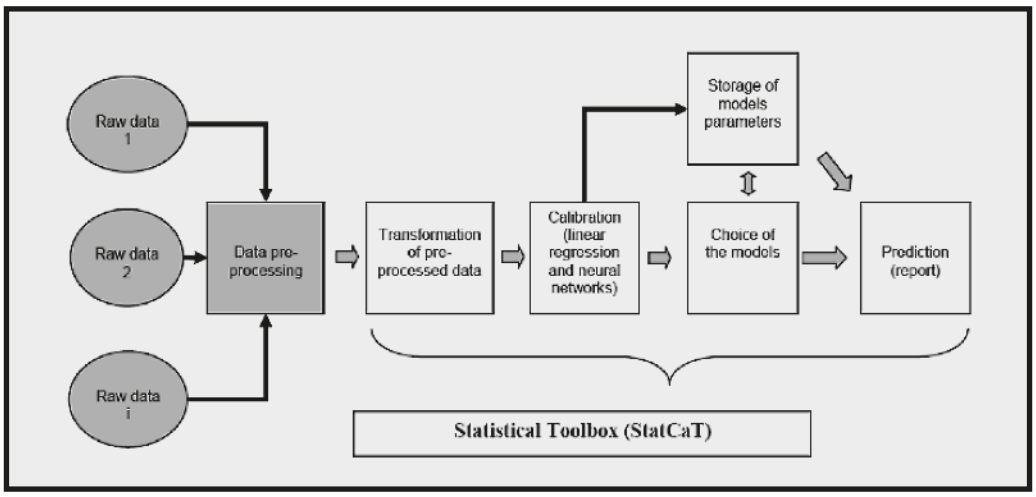
Therefore, to optimize and automate the crop yield forecasting procedure, CRA-W developed the StatCaT statistical toolbox (Figure 1.5), which enables:

Integration of two different statistical methods and softwares (regression analysis and neural networks) into a single statistical toolbox used for crop yield predictions;

- Definition of an endless number of yield indicators on the basis of the pre-processed data available;
- Integration of all these possible yield indicators;
- Use of different calibration models for each possible case;
- Stocking of all the models' calibration parameters such that the predictions can be reproduced at any moment (which is fundamental for the a posteriori evaluation of predictions);
- Decreasing of risks of error;
- Provision of final yield estimations in a report file.

The collaboration between the various national institutions and universities is well-established, and allows for the constant analysis of and harmonization between the crop yield forecasts provided by the B-CGMS and the NIS. Although the B-CGMS is an unofficial source, some of its main clients are the Belgian Ministry of Agriculture, national and regional administrations and, from the agricultural sector, agricultural organizations, farmers, and traders.

FIGURE 1.5.
Flowchart of the data for yield forecasting in the B-CGMS, with the StatCaT Statistical Toolbox



Source: Curnel et al., 2005.

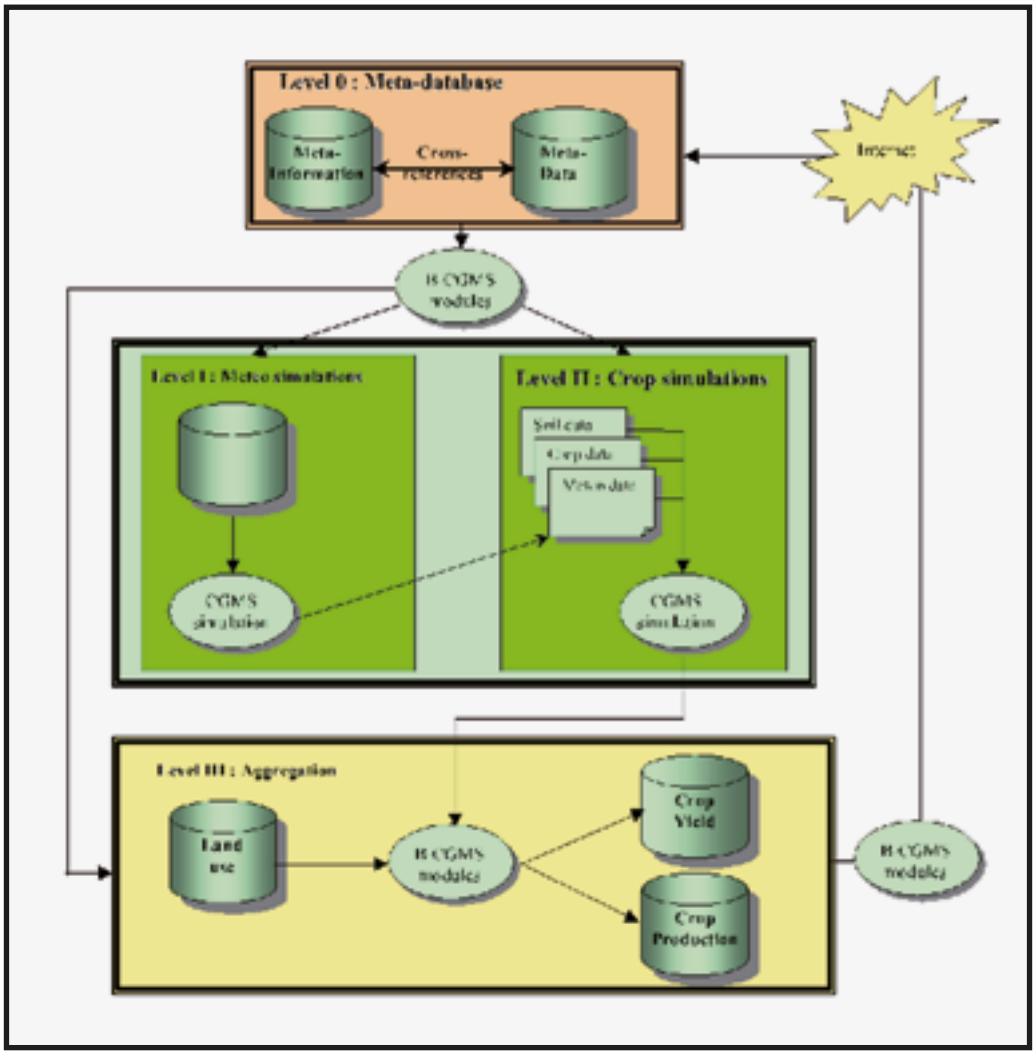
The B-CGMS produces crop yield forecasts that calibrate a number of indicators having different natures. Thus, data re-formatting, harmonization and pre-processing is a key phase of the process. The forecasting procedure has been optimized and automatized by CRA-W through the StatCat statistical toolbox.

This project's objective is to forecast agricultural production at different scales, using remote sensing and an agro-meteorological CGMS – a task that requires teamwork. The three scientific partners involved in the B-CGMS project (i.e. ULg, CRA-W, and VITO) are delocalized institutions and distant from one another. Moreover, the subject is multi-disciplinary and requires a large amount of data, which are highly heterogeneous and must be collected, validated, generated and archived. These operations are performed over time and are not carried out simultaneously. The B-CGMS server is a common starting point for the three partners, and all information is centralized and stored therein. The system has three types of relational databases (Figure 1.6 below):

- a meta-database, to manage the different tables and files;
- a geographic database; and
- a semantic database (input data, simulation results, cropped areas...).
- These databases are managed by two systems, which can be accessed locally or remotely (via Internet):
- a management system and query database (a DBMS); and
- a data analysis system, in the form of maps, graphs and tables (a GIS server).

The B-CGMS implementation has three levels and may be described as a three-tier architecture (Figure 1.7). The GIS client and its browser (the GIS Browser) represent the first level. The dynamic GIS server (GIS Web Server) is the second level, and makes up the core of the architecture. This constitutes the linkage between client requests and the access to databases and data processing.

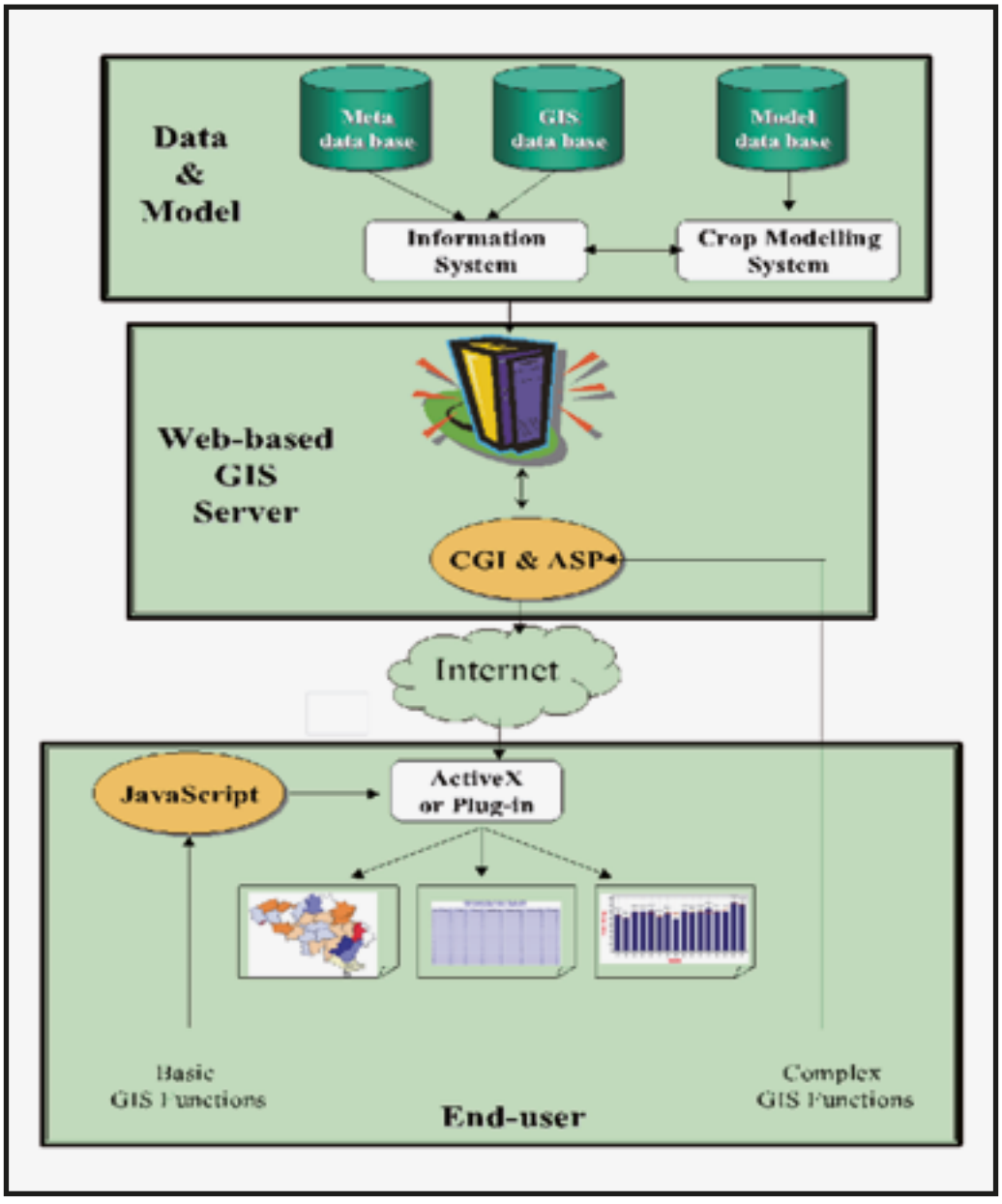
FIGURE 1.6.
Architecture of the B-CGMS database management system



Source: Tychon et al., 2000.

The three types of relational databases form the B-CGMS server: a metadata database, a geographic database, and a semantic database.

FIGURE 1.7.
Architecture of the B-CGMS GIS server



Source: Tychon et al., 2000.

The architecture of the B-CGMS implementation, which may be described as a 3-tier architecture, has three levels: the GIS Browser, the GIS Server, and the Database.

In addition, the B-CGMS system produces an agrometeorological bulletin[44] every three months, providing crop yield forecasts for all agricultural regions for the following crops: winter wheat, winter barley, fodder maize, potatoes, sugar beet and winter rape.

[44] http://b-cgms.cra.wallonie.be/wp-content/uploads/2014/09/BCGMS_Bulletin_2014_09_Fr.pdf

2.5. Human, financial and technical infrastructure

The system established by the NIS falls under the Government of Belgium's agricultural policy. Final estimates of agricultural statistics (yield, area and production) are available online[45] for the years from 2007 to 2013 (at national, regional, provincial and agricultural region levels), as well as provisional production estimates (at national level) for 2014. GIS systems are widely used to represent Wallonia's agricultural features[46].

The system established under the B-CGMS is linked to universities and national institutions involved in agriculture, and is supported by national and international projects (e.g. BELSPO and JECAM[47]). Qualified staff of the four main partners (IRM, CRA-W, ULg and VITO) manages the system remotely. The system also enjoys the strong support of VITO, which an essential partner of the system as it provides a regular supply of remotely sensed imagery and updates to the system with more advanced data, which are obtained with a new type of sensors. The know-how developed within the B-CGMS is then transferred to developing countries in the framework of a specific project (i.e. the Global Monitoring for Food Security project – GMFS[48]).

2.6. Institutional structure and sustainability

The system established by the NIS under the Ministry of Economics, and therefore the institutional structure, is well-established and sustainable.

As mentioned above, the system established under the B-CGMS was created in 1998 to work on a two-year project, financed by BELSPO, to develop a "Belgian" CGMS, with a team composed of members of three institutes: ULg, CRA-W, and VITO. From 2001 to 2006, a bilateral collaboration with the Heilongjiang Province Institute for Meteorological Sciences was funded, with the objective of improving both the Belgian and the Chinese CGMSs. Since 2006, the B-CGMS continued on an operational basis, through voluntary funding from ULg, CRA-W and VITO. Starting in 2015, two new projects (iPOT and BELCAM) funded by BELSPO will support the B-CGMS for four more years, thus enabling technical improvements to be made.

2.7. Innovation and integration with regional- and global-level initiatives

The B-CGMS is an adaptation of the broader CGMS system for EU countries and thus operates in strong partnership with the JRC-MARS Unit, although the two systems use different datasets. Because the system makes use of agrometeorological models and

[45] Agricultural statistics: http://statbel.fgov.be/fr/statistiques/chiffres/economie/agriculture/exploitations/#.VKqr4Xte83Y
[46] GeoPortal for Wallonia: http://geoportail.wallonie.be/en/home.html
[47] JECAM Belgium/France: http://www.jecam.org/?/project-reports/belgium-france
[48] GMFS: http://www.gmfs.info/

remote sensing techniques developed by the JRC-MARS Unit, any technical modifications of the system are made in full collaboration with the Unit.

3. Linking up with crop production forecasts: the practices followed by Belgium's national official sources

3.1. Which area data is used? The methodology applied

The NIS computes production estimates for the main crops by combining the results of two surveys: one on crop acreage and another on crop yield. Concerning crop acreage, a farmers' survey has been conducted in Belgium since 1846, but important changes were made to the system in 1960. Crop acreage, necessary to assess total production, is derived from the IACS of the Ministry of Agriculture, which is responsible for this agricultural survey (De Baets, 1996). The IACS collects farmers' declarations for their requests for crop subsidies from the Ministry of Agriculture (advanced by compiling and submitting the Crop Acreage Declaration for, available in Annex B1.4); these declarations indicate the extent of the cultivated area for all agricultural parcels (± 620,000) over most of Belgium's territory, which for this purpose is divided into 58 observation areas. This agricultural survey is held around 15 May of each year and provisional results, based on approximately 20% of farms, are available by the beginning of October.

As mentioned above, with regard to crop yield, the method established and applied by the NIS since 1995 seeks to be more objective, as it is based on measuring the quantities harvested within selected farms; indeed, the previous method was based on expert judgments within the agricultural circumscriptions and sometimes led to underestimations. The preliminary survey on crop yield is conducted in August, by approximately fifty agricultural officers, who are supervised by ten official agronomists. This estimate, combined with the preliminary results of the crop acreage survey conducted in May, is used to obtain a preliminary estimate of crop production at national, regional, provincial and agricultural regions levels by early October of the current year. During the second phase, the final crop yield estimate is obtained on the basis of information gathered by the agricultural officers during the month of December from a sample of 1,500 farms, which represent about 5-10% of total crop acreage and approximately 2.5% of total farms. The final crop production estimate is released by 1 October of the following year (De Baets, 1996).

However, the survey methodology for estimating crop production was revised in 2014. The method whereby the estimate was obtained in two phases (a preliminary estimate followed by a final estimate) has been discontinued, and one single survey is conducted since January 2015. This survey seeks to determine the production of the main crops harvested

in 2014[49]. Preliminary yield estimates are based on information received from professional organizations and on estimates compiled by the NIS. The total crop acreage will be derived from administrative data collected from the Crop Acreage Declaration forms at regional level.

Although its main task is determining crop yield forecasts, the B-CGMS also collects detailed information on crop acreage, to estimate their final production. In May every year, the first declarations are introduced into the IACS; at the end of the month, the first acreage estimates for the different crops can be progressively computed until the end of September (see Table 1.5). However, due to sampling problems (essentially due to the fact that the encoding is not random), the information must be translated into a transition matrix, based on the yearly change of each parcel's occupation with a given crop. These matrices provide the probability of a parcel changing occupations and are set up on the basis of observations obtained during the previous agricultural season. During the new season, they are progressively updated with new data, in accordance with a statistical process using Markov chain properties. This approach provides improved estimates of the various crops' acreage during the season. It is also more precise than the European approach and allows the B-CGMS to predict not only yield, but also production, at an early stage of the cropping season (Piccard et al. 2002).

TABLE 1.5.

Timing of database updates concerning B-CGMS agricultural parcels

Availability	Agricultural parcels (#)	Percent of total number
End of May	115,570	19
End of June	267,558	45
End of July	374,582	62
End of August	489,090	82
End of September	598,853	100

Source: Piccard et al. 2002.

3.2. Release calendars: punctuality and timeliness

The NIS estimates crop production by combining the results of two surveys: one of the cropped area and another on the yield (further details are available in Section 2.1 above).

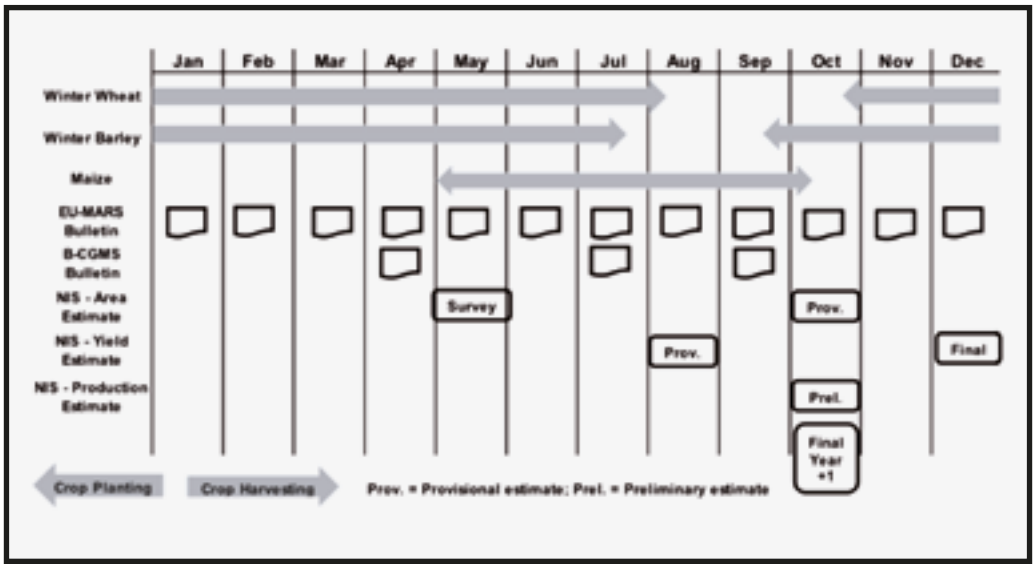
As mentioned in Section 1.3, the B-CGMS produces an agrometeorological bulletin every three months, providing crop yield forecasts for all agricultural regions and covering a specific set of crops. The system also assesses crop production by using the exact crop surfaces available from the Belgian Ministry of Agriculture's IACS.

EU-MARS releases monthly bulletins from January to December (see Section 1.3 above).

[49] For the provisional estimate of crop production for 2014, see http://economie.fgov.be/fr/modules/publications/statistiques/economie/downloads/agriculture_-_estimation_de_la_production_des_cultures_agricoles_2014.jsp.

Table 1.6 provides a complete description of the release frequency of yield forecasts and estimates, and acreage and production estimates in Belgium, together with the main crops' planting and harvesting calendars.

TABLE 1.6.
Crop calendars and release frequency of crop forecasts and estimates



3.3. Human, financial and technical infrastructure

The system established under the B-CGMS was created in 1998 to work on a 2-year project financed by the BELSPO aiming to the development of a "Belgian" crop growth monitoring system with a team composed of members of three institutes: ULg, CRA-W, and VITO. From 2001 to 2006, a bilateral collaboration project with the Heilongjiang Province Institute for Meteorological Sciences was funded with as objective improving both Belgian and Chinese Crop Growth Monitoring Systems. Since 2006, the B-CGMS continued on an operational base through voluntary funding from ULg, CRA-W and VITO. Starting in 2015, two new projects (i.e. iPOT, BELCAM) funded by BELSPO will support B-CGMS for 4 more years and will allow for technical improvements.

3.4. Institutional structure and sustainability

The system created by the NIS under the Ministry of Economy – therefore, the setup – is well-established and sustainable. Final estimates of agricultural statistics (yield, area and production) are available online[50] for the years from 2007 to 2013 (at national, regional, provincial and agricultural region levels) as well as provisional production estimates (at

[50] Agricultural statistics: http://statbel.fgov.be/fr/statistiques/chiffres/economie/agriculture/exploitations/#.VKqr4Xte83Y

national level) for 2014. GIS systems are widely used to represent Wallonia's agricultural features, such as land use[51] (see Figure B1.5, Annex B1.1).

The system established under the B-CGMS was created in 1998 to work on a two-year project, financed by BELSPO, to develop a "Belgian" CGMS, with a team composed of members of three institutes: ULg, CRA-W, and VITO. From 2001 to 2006, a bilateral collaboration project with the Heilongjiang Province Institute for Meteorological Sciences was funded, with the objective of improving both Belgian and Chinese CGMSs. Since 2006, the B-CGMS continued on an operational base through voluntary funding from ULg, CRA-W and VITO. Starting in 2015, two new projects will support the improvement of B-CGMS.

[51] Land use in Wallonia: http://cartopro3.wallonie.be/CIGALE/viewer.htm?APPNAME=COSW&APPMODE=VIEWER

2

Crop Yield Forecasting in China

Ning Zhang[1]

1. Crop yield forecast data for China

1.1. Brief description

China is the first world producer of wheat and rice and is a major producer of maize and soybean. It successfully feeds approximately 20 percent of the world's population, with less than 10 percent of arable land. Crop production in China has a direct effect on its people's livelihood, the nation's economy and social development and the world food[2] demand and supply balance.

Being the most important priority in sustaining human society, crop production and yield estimation have always received great attention in China. In recent years, the Chinese government and society have made substantial efforts to develop and adopt innovative methods to improve accuracy and timeliness in providing agricultural services, such as crop yield forecasts. This Chapter will begin with an overview of the current domestic and international resources employed to compute crop yield estimates and forecasts in China.

[1] Institute of Remote Sensing and Digital Earth, Chinese Academy of Science.

[2] Notes on terminology: in Chinese sources, "grain" includes cereals, beans and potatoes, while it may also be categorized as summer grain, early rice and autumn grain depending on the production season. "Total grain production" refers to the total of cereals, beans and potatoes produced in a given region in one production year. "Food" includes, in addition to "grain," edible vegetable oils, meat, poultry, dairy and marine products.

1.2. Inventory of forecasts available, by source

1.2.1. Official national sources

1.2.1.1. The National Bureau of Statistics

The National Bureau of Statistics (NBS) of the People's Republic of China is directly under the control of the State Council and is in charge of statistics and economic accounting. It is a main provider of national statistical data and a coordinator of government departmental statistics and local statistics for the entire national statistical system (China 2015b). The NBS releases the official statistics for grain production and farmers' disposable income.

The NBS serves as the official dissemination body for China's national crop production estimates. To produce these estimates, essentially two approaches are available: (1) the traditional approach, based on sample surveys combined with the complete reporting system, and (2) the remote sensing (RS) operation system (the National Statistics and Remote Sensing System of Crop Production – NSRCP).

The crop yield forecasts obtained through the NSRCP are used only as internal references to the crop estimates generated by traditional statistics and are not disseminated to the public.

1.2.1.2. The Ministry of Agriculture

The Ministry of Agriculture (MoA) of the People's Republic of China is a component of the State Council and is in charge of agriculture and rural economic development. It is responsible for forecasting and publicizing rural economic information on various agricultural products and means of agricultural production, and for formulating agricultural and rural economic development strategy plans (China 2015a). To supervise the results of policy implementation, the MoA also collects a range of agricultural and rural statistics, which complement China's overall agricultural and rural statistical system (Zhao and Zhou 2010).

Similarly to the NBS, the MoA may adopt either of two different approaches to produce agricultural crop estimates and forecasts: (1) the traditional method for computing crop estimations for each province are the complete reporting system and sampling survey; while (2) the China Agriculture Remote Sensing Monitoring System (CHARMS) is a new source of crop forecasting data in the main grain-producing provinces. CHARMS was developed by the MoA's Remote Sensing Application Center (RSAC) to provide agricultural information on crop condition, crop area, yield and production, as well as agriculture disasters analysis for five major crops (wheat, rice, maize, soybean and cotton; Huang et al. 2009).

1.2.1.3. The China Meteorological Administration

The China Meteorological Administration (CMA) is a public institution that is directly affiliated to the State Council. The CMA has prioritized the provision of agrometeorological services for several years now.

Beginning in the 1990s, the CMA's agrometeorological yield forecasting system was gradually

established, at national, provincial, prefectural and county levels. With the development of spatial technology and the launch of Chinese meteorological satellites (FY-series), pilot studies on crop monitoring and forecasts using RS were also initiated. Today, various crop monitoring and yield forecasting systems have been developed and are used for routine meteorological work in regional meteorological bureaus. The CMA has established an integrated meteorological observing system that incorporates space-based, airborne and ground-based observations; this system has provided significant technological and facilities support to national yield forecasts and agrometeorological services (CMA 2015).

1.2.2. Non-official national sources

In addition to the official national organizations, many research institutes, universities and enterprises conduct research on yield forecasts and offer forecasting services.

A research team headed by Chen Xikang at the Academy of Mathematics and System Science, Chinese Academy of Sciences (AMSS/CAS) is experienced in computing annual yield predictions of China's grain, cotton and oil crops on the basis of mathematical statistics. This team has proposed a systematic integrated method that takes into consideration the effects of agricultural inputs, technological advancements, natural factors such as climate and pests, and policies on grain output. The key technique consists of three types of elements: a combination of the input-occupancy-output analysis (an extension of classical input-output analysis), nonlinear variable coefficient forecasting equations and the minimum sum of the absolute values (Chen and Guo 1992; Chen et al. 2001; Chen and Yang 2002). This approach has been successfully implemented in China since 1980. Every May, the team submits an annual report on grain output prediction. The bumper, average, and poor harvests are correctly predicted every year, and the average error rate over the period 1980–2004 is 1.9 percent (compared to official statistics releases: Chen et al. 2008). However, this high accuracy is achieved at a high cost: a great amount of manpower, financial resource data and other ancillary data are necessary.

CropWatch is a global crop monitoring system that uses mainly RS data, combined with selected field data, to provide analyses of the global production of major crops (maize, wheat, rice and soybean) and environmental and agricultural trends (Wu et al. 2010a). This system was developed in 1998 and operated by the research group led by Professor Wu Bingfang at the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences (RADI/CAS). Over the years, CropWatch has been updated regularly, as new data sources or remote sensors and methodologies have become available (Wu 2000; Wu et al. 2010b). A 2014 upgrade of CropWatch has extended its monitoring scale to four spatial levels: global (65 global crop Monitoring and Reporting Units – MRUs), regional (seven Major Production Zones – MPZs), national (31 key countries covering 80 percent of the world's major crop exports and production), and sub-national (provinces/states of the main target countries, especially China) units (Wu et al. 2015). A hierarchical set of novel crop indicators has been developed for key crop information, including crop condition, cropping intensity, crop planting area, crop area proportion, yield and production, as well as a grain supply-demand balance analysis (Wu et al. 2014; Wu et al. 2015) in which the crop area, yield and production are available at national and sub-national levels (Meng et al. 2004, 2011; Xu et al. 2008). The yield

and production can be predicted one month prior to harvest. The validated accuracy of the CropWatch system is 80 percent for crop condition monitoring, 95 percent for area estimation of major crops, 94 percent for yield prediction, and 92 percent for production estimation. (Li and Wu 2004; Zhang et al. 2004a; Li 2008; Wu and Li 2012; Wu et al. 2014). Each quarter (every February, May, August and November) the crop monitoring and forecasting results are published in a CropWatch bulletin, which is issued in both English and Chinese and may be downloaded from the CropWatch website[3], together with value-added products and specifications on methodology.

Due to the large-scale, fast and cost-efficient availability of satellite data, RS technology has also been widely used in several universities, provincial governments and emerging technology corporations. Zhejiang University (Tang et al. 2004; Peng 2009; Huang et al. 2013), Beijing Normal University (Gao et al. 2012; Jin et al. 2012; Zhao et al. 2014), China Agricultural University (Su et al. 2011; Huang et al. 2012a) and Nanjing University of Information Science and Technology (Shen et al. 2009; Yang et al. 2009a; Chen et al. 2013) have all adopted RS to research the yield estimation of wheat, maize, rice and cotton at provincial, county, township and even village levels, with estimation accuracies ranging from 85 percent to 97 percent. Several RS centres have been set up at provincial level, especially in Jiangxi, Shaanxi, Heilongjiang, Hubei, Henan, Jilin and Jiangsu provinces, and incorporated in routine agricultural monitoring and crop forecasting. Several technology corporations, such as Zhengzhou Hualiang Technology Co. Ltd. (with the China Grain Net[4]), Hexun Technology Co. Ltd.[5] and Wuhan Jiahe Technology Co. Ltd.[6] provide customized crop monitoring and yield forecasting services for different countries and at customized scales, based on RS, Geographic Information Systems (GISs) and big data. The China Grain Net, established in 1995, is the earliest, largest and most comprehensive and professional web portal for the grain industry in China, and provides production estimations one month before harvest. Hexun Technology issues the earliest forecasts, available three months before harvest, with an average accuracy of 90 percent; the average accuracy of estimates two months prior to harvest reaches 95 percent[7].

1.2.3. Other regional/global sources

Information on grain is also available from international sources. In the United States, the US Department of Agriculture's (USDA) Foreign Agricultural Service (FAS) offers global crop information as part of its Global Agricultural Monitoring (GLAM) program (Becker-Reshef et al. 2010). The GLAM program releases monthly reports on the current USDA forecasts of crop area, yield and production of major countries worldwide, and is freely available in the World Agricultural Supply and Demand Estimates (WASDE, http://www.fas.usda.gov/data/world-agricultural-production). The sources include reporting from FAS's worldwide offices, foreign governments' official statistics, and analyses of economic data and satellite imagery.

[3] CropWatch: http://www.cropwatch.com.cn/htm/en/index.shtml
[4] China Grain Net: http://www.cngrain.com/
[5] Hexun Technology Co. Ltd: http://www.data3e.com/
[6] Wuhan Jiahe Technology Co. Ltd: http://www.datall.cn/
[7] http://www.data3e.com/products_dzong.html, in Chinese

1.3. Release calendars: punctuality and timeliness

The NBS's crop yield forecasts obtained through the NSRCP are used as internal references to the crop estimates generated by traditional statistics. The yield forecasts are internally reported in three reports: a preliminary report, a pre-production report and a final production report, while the planting area is reported annually (Zhang et al. 2010).

The crop production estimates are released at the press board of the NBS's website[8] in mid-July, at the end of August, and in early December for summer grains, early rice and national grain output respectively. A detailed timeline of NBS's internal crop estimates (China 2014b) is provided in Table B2.1, Annex B2.1.

As for the MoA's CHARMS, the change in the crop sown area can be determined one month before harvest and the crop production can be forecast every month at late growing stages, with the final estimation being delivered by May, September and early October for winter wheat, maize and cotton respectively (Yang 2007).

Each province regularly reports the crop estimates based on the traditional method (a complete reporting system supplemented by sampling surveys) to the MoA (see Table B2.2, Annex B2.1; China 2013), and the CHARMS crop forecasts are disseminated internally. Both sources are reported to the State Council and are used internally for policymaking purposes and to supplement the NBS's official agricultural statistics.

The CMA's agricultural forecasts are released through multiple channels. Internally, two national consulting conferences are hosted by the CMA every year (mid-May and late August) to assess the national yield of summer crops and autumn crops. Representatives are invited from all provincial meteorological bureaus and other official department and institutions, including the MoA, the NBS, the State Administration of Grain (SAG), the Ministry of Civil Affairs (MCA) and the Chinese Academy of Sciences (CAS). Externally, the critical agrometeorological updates are directly reported to the State Council, the Rural Work Leading Group of the Communist Party of China's (CPC) Central Committee, the National Development and Reform Commission (NDRC), the Ministry of Finance (MoF), the MoA and other relevant government departments; the crop forecasts may be updated in the periodical Agro-Meteorological Bulletins with ten-day, monthly, seasonal or annual time periods. Besides, during important growing periods for specific crops, special topic reports are issued to enable the dynamic monitoring of crop conditions and yield prospects. In addition, Agro-Meteorological Disasters Reports are released when disasters occur (Wang and He 2009). Currently, the CMA is capable of obtaining the variation of average, yield and production (increase or decrease) of domestic crops two months before the harvest, and the quantitative estimation of yield and production one month before harvest. For foreign countries such as United States, India and Brazil the yield predictions are available one month before harvest.

[8] NBS press board: http://www.stats.gov.cn/english/PressRelease/

1.4. How do these different forecasts compare? Purpose, coverage, scale and harmonization issues, accuracy

The NBS is the only official body that releases crop estimates for China, thus providing a unified crop data outlet. Although the official organizations (the NBS, the MoA, and the CMA) conduct crop forecasts separately, they all directly report to the State Council and the forecasting results are for internal use only. The crop information is well-referenced and shared among the official organizations. As mentioned in Section 1.2.1.3 above, the CMA organizes two consulting conferences on grain production each year, with expert participants from the MoA. In addition, as the ultimate coordinator of China's statistical system, the NBS uses the agricultural information provided by the MoA and the CMA as the basis for the official Agricultural Statistics. Therefore, the official Chinese sources of crop estimates and forecasts are highly harmonized.

The non-official sources may provide separate references, flexible forecasts and more openly accessible information compared to official releases. Unlike official national organizations, which enjoy significant funding to build top-to-down survey offices and teams, information centres, observing stations and networks throughout the country, the non-official institutes and organizations rely mainly on advanced technology, such as RS, to offer crop services in a more flexible, focused and fast manner. In addition, the prediction results are generally freely accessible from publications, reports and websites. Although there may be some deviation and differences between the official and non-official results due to the sampling, statistical methods and basic data used, the non-official sources do provide an independent reference and more timely and detailed information.

A detailed comparison of the coverage, accuracy, release frequency and accessibility of the various sources is provided in Table 2.1.

TABLE 2.1
Comparison of the sources of crop forecasts for the People's Republic of China

Crop Forecasts				
Sources	**Coverage**	**Accuracy**	**Release Frequency**	**Accessibility**
NBS	National and provincial	Area and Yield: 95% with NSRCP[9]	Crop planting area is reported annually; Crop yield is reported in three reports: preliminary report, pre-production report and final production report	Internal Use Only
MoA	National and provincial	Yield: Greater than 88% using CHARMS[10]	Change of crop sown area is determined one month before harvest; crop production is forecasted every month at late growing stages with the final estimation by May, September and early October for winter wheat, maize and cotton respectively	Internal Use Only
CMA	National and provincial	Yield and Production: 98% for domestic, 95% for overseas[11] Area: 95%[12]	Yield variation is generally predicted two months before harvest; Quantitative yield is forecast one month before harvest; Annex 4, Table A.3	Internal Use Only; Report to State Council
AMSS/CAS	National and provincial	Production: 98%[13]	Every May	Internal Use Only; Report to State Council
RADI/CAS	Global, national and provincial	Area: 95%; Yield: 94%; Production: 92%[14]	Every February, May, August and November	Openly accessible at http://www.cropwatch.com.cn/en
Universities	Provincial, county and township	Yield: ranges from 85% to 97%[15]	Irregular	Published in research papers
Companies	Customized country and scale	Area, Yield and Production: Ranges from 90% to 95%[16]	Customized (one to three months before harvest)	Customized and authorized
FAS/USDA	Global, national		Updated monthly	Openly accessible at http://www.fas.usda.gov/data/world-agricultural-production

[9] See Zhang et al. 2010.
[10] See Teng et al. 2012; Ren et al. 2008; Chen et al. 2011.
[11] See China Meteorological News 2014.
[12] See Xu et al. 2007.
[13] See Chen et al. 2008.
[14] See Li 2008; Wu and Li 2012; Wu et al. 2014.
[15] See Tang et al. 2004; Huang et al. 2013; Gao et al. 2012; Jin et al. 2012; Zhao et al. 2014; Shen et al. 2009; Yang et al. 2009a; Chen et al. 2013.
[16] See http://www.data3e.com/products_dzong.html (in Chinese).

2. China national official sources: methodology and practices

2.1. Description of the official yield forecasting methodology

As a large grain-producing country with a vast territory and fragmented cultivation area, crop production and yield forecasting in China is a complex endeavour, and various methodologies are applied by the different organizations and departments involved. This Section describes the methodology and practices concerning grain statistics in general and yield forecasts in particular adopted by the official crop information providers: the NBS, the MoA and the CMA.

2.1.1. Methodology and practices of the National Bureau of Statistics

In the NBS, grain statistics may be retrieved from two sources: (1) the traditional statistical system, which can provide production estimates during the crop harvest season, and (2) the RS operation system, which is used to obtain crop forecasts prior to crop harvest. Figure 2.1 below illustrates the structure of each system.

To obtain grain production statistics using the traditional method, two approaches are applied together: the complete reporting system and the sample survey. The complete reporting system is the oldest statistical method, adopted by the NBS in the 1950s. It is based on the hierarchical administrative structure: the estimates and reports from the basic village level are transferred to the township level, are then summarized at county level and next at province level, and are finally aggregated to generate the national totals. The information collected from the village level includes the number of households, the labour force, crop acres planted, crop yields, and livestock numbers (Vogel 1999). Reports on grain production are generally issued three times a year, on 15 July for summer crops, 20 August for early rice and 30 November for autumn crops; other agricultural products (except livestock products) are reported annually by 20 January of the following year. A detailed timeline of NBS internal crop reports (China 2014b) is available in Table B2.1, Annex B2.1.

This bottom-up reporting system has obvious and inherent problems, such as those arising due to human manipulation and uncertain data quality and accuracy (indeed, the final accuracy depends on the accuracy of each previous level, and no individual farm or household data are available for county or higher levels for evaluation). To address these issues and obtain more objective, accurate and timely data, in the 1980s the NBS introduced the sample survey.

The sample survey is based on administrative institutions at three levels: the NBS's Division of Agricultural Survey is in charge of the rural socio-economic sample survey at national scale. At provincial level, the NBS survey offices established in 31 provinces (autonomous regions and municipalities) each manage the crop sampling survey in their respective provinces and submit the final estimates to NBS on a regular basis. The NBS survey offices at county level are responsible for conducting surveys in all sample villages (Pan et al. 2010). The sample villages are assigned by the provincial survey office, using the Probability Proportional to Size (PPS) method, while staff members and assistant interviewers from county survey offices

apply the systematic sampling method to select the sample fields with equal probability within the sample villages (Zhao and Zhou 2010).

With the development of spatial information techniques such as "3S", namely RS, GISs, and Global Positioning Systems (GPSs), the NBS has made great efforts to modernize the traditional statistical system. Since the 2000s, RS was introduced in the design of the sampling frame, which constitutes the core of the area sample survey and the basis of the yield sample survey (Pan et al. 2010). Gradually, use of the list sampling frame evolved towards that of the area sampling frame. Since 2013, the NBS has officially implemented crop production area frame sample surveys in Jiangsu, Henan, Liaoning, Jilin, and Hubei provinces (Xu and Zhou 2013). The design and assessment of the area sampling frame are introduced by Wang and Wei (2014), and its application in area sample surveys is briefly introduced in Section 3.1 below. In addition, the NBS's information infrastructure for agricultural statistics has been updated. High-tech apparatuses and instruments such as GPS, Personal Digital Assistants (PDAs), Unmanned Aerial Vehicles (UAVs) and agricultural variable collectors were used in the NBS's agricultural measurements, enhancing the efficiency of ground surveys. Currently, a project on the Fast Agricultural Survey Platform is also being designed in the NBS; this project aims to combine the rapidity of surveys of crop growth conditions, planting area, yield and impact of disaster with satellite data and fast survey vehicles equipped with high-tech survey devices (Wei 2013). Moreover, modern information and communication technology also enhances the efficiency, objectiveness and harmonization of agricultural statistical work. A dedicated network with an online reporting system has been introduced in all NBS survey organizations, from national and provincial to county levels, and specialized unified data processing programs are used in the survey for data entry, checking and editing (Xu and Zhou 2013).

2.1.1.1. The remote sensing operation system

In 2003, the NBS collaborated with other universities and research institutes to launch a research on combining national agriculture statistical survey systems with RS technology. Several experiments were conducted on the use of multi-scale RS surveys on typical crops (wheat, maize and rice) from Henan, Hebei, Anhui, Shandong and Jiangsu provinces, and compared with statistical sample survey results. In 2006, the Ministry of Science and Technology established the first key project ("National High Technology Research and Development Program 863") in the field of "Earth Observation and Navigation Technology: Research and Application of Key Technologies of National Statistics and Remote Sensing Service System". This led to the development of the NSRCP, which aims to comprehensively combine the country's current survey system and 3S technology to produce accurate estimates of crop area and yield statistics for the major crops (wheat, corn and rice) at provincial and county levels (Zhao et al. 2007). The NSRCP has been operated in five main grain-producing provinces (Jilin, Henan, Jiangsu, Hunan and Beijing) with an expected accuracy of planting area and yield at county-level greater than 95 percent. The structure, functions and application of the NSRCP have been examined by Zhang et al. (2010). Its key technologies are outlined below.

The NSRCP's key technology includes a geospatial framework, a ground-support network, planting area measurement, and growth monitoring and yield forecasting. The first two are the system's basis and database, and the latter two are the NSRCP's core functions. The right-hand graph in Figure 2.1 below illustrates the yield forecast methodology adopted in the NSRCP system. In the yield forecasting function, the multi-type and multi-resolution RS data are used as major data sources (including MODIS, HJ-1 and Landsat TM), together with ground sample data (including crop planting area, crop area proportion and crop yield), bio-meteorological data, historical yield statistics and other geographic auxiliary information (including administrative division maps, yield regionalization maps and crop distribution maps). These data are comprehensively applied to multiple yield estimation models, such as the real-measurement based model, the meteorological yield model, the statistical yield model and the crop growth simulation model. The forecasting results from the different statistical and process-based models are then compared and combined to achieve a final crop yield prediction.

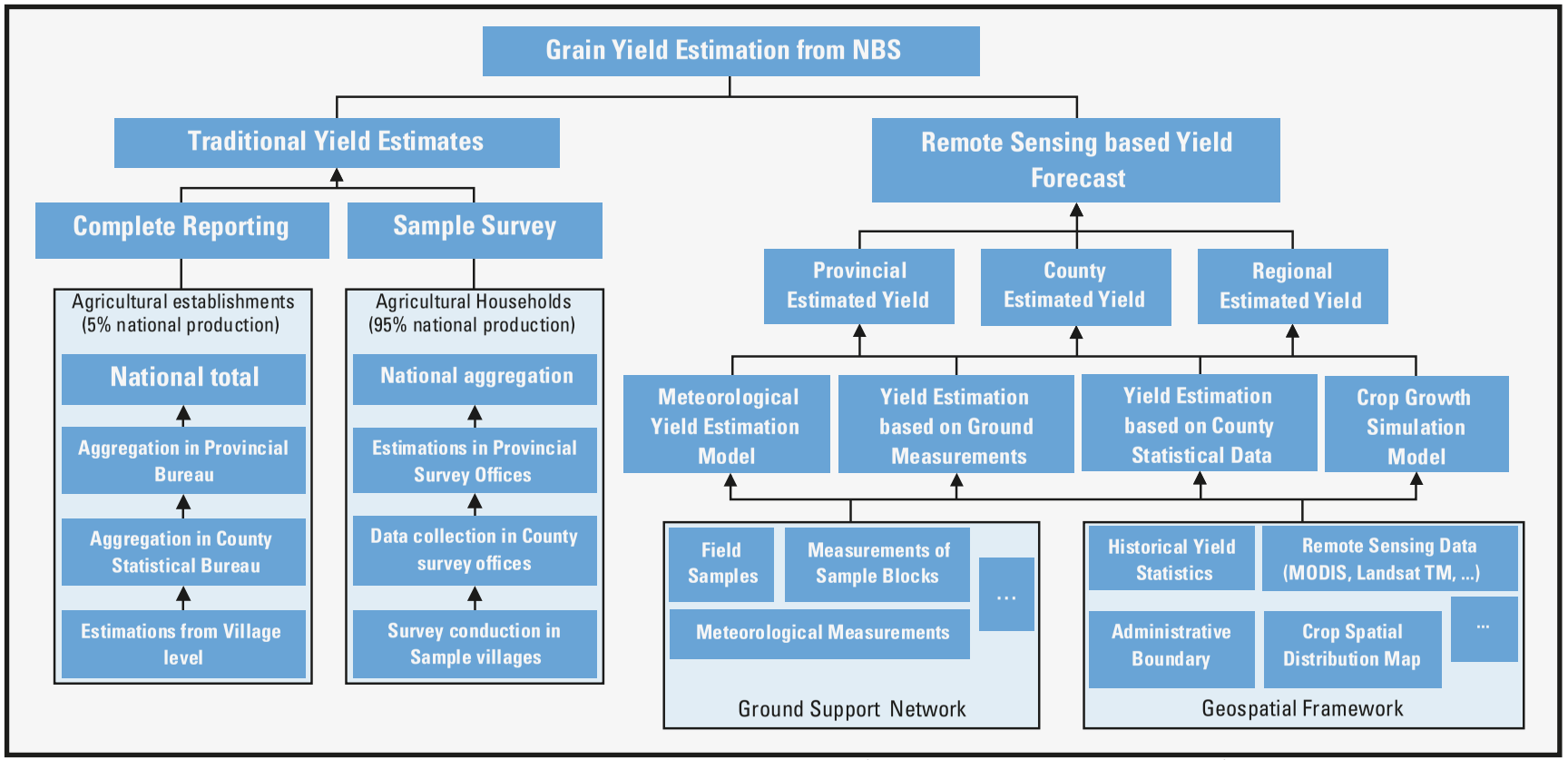
Currently, the NBS adopts both traditional statistical and RS-based methods, both of which have advantages and disadvantages. Table 2.2 below compares the traditional method and the RS method in terms of application scale, infrastructure, efficiency, objectiveness and harmonization, accuracy and sustainability.

TABLE 2.2
Comparison between traditional statistics and RS-based statistics

	Traditional statistical method		RS operation system
	Complete reporting system	Sample survey	
Application scale	National (aggregate from all administrative levels)	National (survey conducted at county and sub-county levels, output estimation is made at provincial level)	Several main grain-producing provinces (sample surveys conducted at typical county and sub-county levels)
Infrastructure	Bottom-up structure; statistical bureaus at province and county levels	Based on list sampling frame; survey offices and teams at province and county levels	Based on area sampling frame; sample survey teams at county and village levels
Efficiency, objectiveness, harmonization	Influenced by artificial and subjective factors; data inconsistencies may arise; data on individual farms or households are not available at a higher level for evaluation and checks	Great financial and labour resources required; long time period for field survey; increased objectiveness and harmonization through dedicated network and regulated field survey	Relatively time- and labour-saving; improved objectiveness with more data sources (RS) for accuracy assessment; multi-source and multi-scale RS data and spatial information facilitate data harmonization
Accuracy	Depends on the initial accuracy of the village head's report and the aggregation accuracy of each lower level.	Although the NBS has overall quality control over survey design, data collecting and processing, the accuracy of sampling surveys has not been released.	Expected to be greater than 95% for planting area and yield estimation at county level (Zhang et al. 2010).
Sustainability	Plays a minor part in the current statistical system and will be completely replaced by sample surveys in the near future.	Plays a major part in the current statistical system and will be incorporated with RS for national statistics.	Has been operationally applied in several provinces and will be applied to all main grain-producing provinces in the future.

FIGURE 2.1

The National Bureau of Statistics' general methodology for yield estimation



The NBS computes crop yield estimates and forecast resorting to two different data sources: 1) the traditional reporting system and 2) the remote sensing system. Both systems are characterized by a complex methodological structure.

2.1.2. Methodology and practices of the Ministry of Agriculture

The crop information and statistics released by the MoA can also be obtained through two different approaches, the traditional one being the complete reporting system supplemented by a sampling survey (Zhao and Zhou 2010), and the new one being CHARMS. Similar to that of the NBS, the MoA's complete reporting system is based on statistical work from agricultural departments (bureaus) at different administrative levels. The statistical department within each agricultural bureau is responsible for collecting crop information from the lower levels and for reporting aggregated crop estimates to higher levels, through unified tables and a dedicated network. For the county-level crop output, sampling surveys are only conducted in the major grain-producing provinces. A detailed internal report timeline of MoA crop estimates (China 2013) is available in Table B2.2, Annex B2.1.

The technological and social advancements have made it possible to replace the traditional statistical system with an RS monitoring system. Therefore, the following sections will focus mainly on the methodology based on an RS system – CHARMS.

2.1.2.1. The remote sensing monitoring system

CHARMS has been operated by the MoA's RSAC since 1999 (Chen et al. 2011). It provides agricultural information on crop condition, crop area variation, yield and production estimation and agriculture disaster monitoring (including for disasters such as drought, floods, frost damage, pest diseases) for five major crops including wheat, rice, maize, soybean and cotton. Other crops are being gradually added to the system. The crop yield estimation module is one of CHARMS' main components, and integrates RS, GISs, ground sampling and various yield forecasting models to estimate the various crops' yield in China's main grain-producing regions. Two yield models are generally used for yield forecasts: the NDVI-based statistical model (Ren et al. 2008) and the Crop Growth Monitoring System (CGMS) (Huang et al. 2011).

I. The Normalized Difference Vegetation Index-based statistical yield model

The basic idea behind this statistical model, based on the research conducted by Ren et al. (2008), is to establish the relationship between the crop production and the spatial accumulation of the Normalized Difference Vegetation Index (NDVI). A stepwise regression is used to select the critical estimation period and optimize the parameters. Then, the yield estimation is computed from the estimated production by dividing the crop planting area. Figure 2.2 below illustrates the flow chart for this methodology. The procedure consists of the four steps set out below (Chen et al. 2011):

(1) Data pre-processing and NDVI preparation. The pre-processing of RS images includes geometric correction, radiation calibration, reprojection, and atmospheric correction. Then, the NDVI is computed by calculating the normalized difference between the red (Rr) and the near-infrared (Rnir) bands of RS data with Equation 2.1:

$$NDVI = \frac{R_{nir} - R_r}{R_{nir} + R_r} \qquad \textit{Equation 2.1}$$

The crop arable land and crop-specific mask from the MoA's RSAC are used to extract the NDVI on crop pixels in an RS image, after the Savitzky–Golay filter has been applied to smooth any noise or disturbance that may affect the data. In addition, the NDVI ranges from 0.2 to 0.8 are selected for further analysis, to consider the NDVI's response to vegetation greenness and biomass.

(2) Preliminary yield estimation. The NBS's historical crop production statistics are used to build the relationship with the spatial accumulation of the NDVI at different growth stages, using Equation 2.2:

$$Y = a + b \times \sum NDVI \qquad \textit{Equation 2.2}$$

Here, Y is the estimated crop production at county level; $\sum NDVI$ is the spatial accumulation of crop NDVI from 0.2 to 0.8 in a county in a given period; a is the constant and b is the coefficient. Stepwise regression is used to determine the optimal period from among all stages, using the criteria that the probability-of-F-to-enter was lesser than 0.10 and the probability-of-F-to-remove was greater than 0.11. The average yield is derived from the NBS's predicted production and county crop planting area.

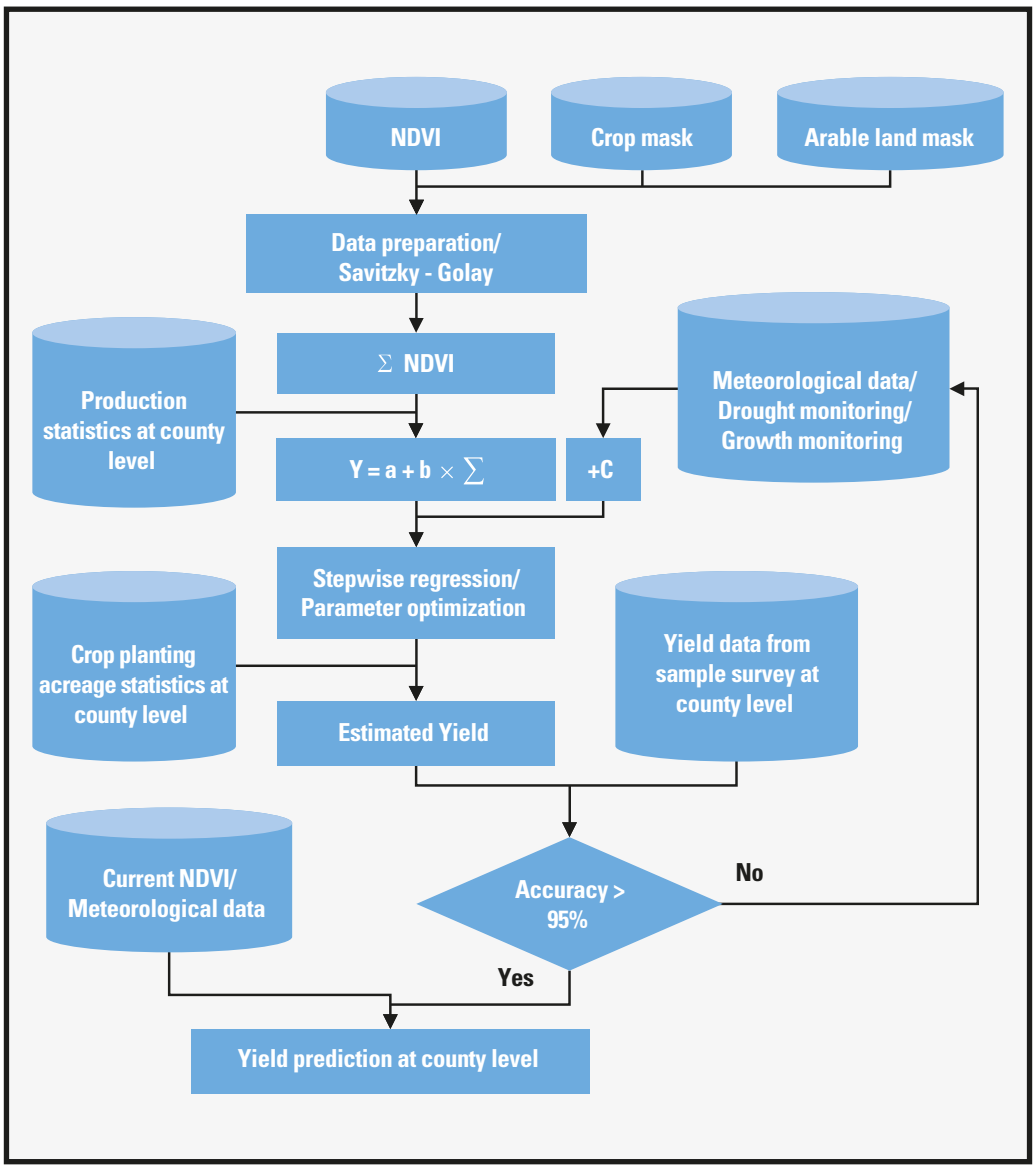
(3) Yield validation. The estimated yield is then compared with the observed yield data from ground samplings at county level. If the accuracy is lesser than 95 percent, which means that the growth conditions are different from those existing during an average year, then the meteorological data, drought indicators or other crop condition indicators are added to refine the yield prediction model, using Equation 2.3:

$$Y = a + b \times \sum NDVI + C \qquad \textit{Equation 2.3}$$

in which C is the correction term based on data from the CMA's meteorological stations or other drought and crop growth indicators derived from various data sources, such as MODIS, Landsat TM, CBERS, SPOT and HJ-1. A new yield estimation will be generated and examined by repeating the second and third steps.

(4) Once the yield model is calibrated, the NDVI data for the current season can be used to predict the average yield of specific crops for the current year, in each county. The yield at county level can then be aggregated to obtain the yield at provincial level.

FIGURE 2.2
Flow chart of NDVI-based statistical model in CHARMS



Source: modified from Chen et al. 2011

The implementation of the NDVI-based model is articulated in four main steps: 1) the pre-processing of data and the preparation of the NDVI; 2) the preliminary estimation of yield; 3) the yield validation; 4) and the yield prediction.

II. The Crop Growth Monitoring System

The CGMS was originally developed by the European Union Joint Research Centre (JRC) on the basis of a crop growth simulation model (the WOFOST) to compute regional yield estimations for major crops. A CGMS is a simplified representation of crop growth and development based on mathematic models. This process-based model is capable of

integrating various factors that affect crop growth, including soil moisture, air temperature, wind speed, fertilization and management skills, to simulate the crop growing conditions and to predict crop yield for a different period. In 2010, the CGMS was built into CHARMS by adjusting and localizing the database, crop parameters and monitoring scale to China's particular conditions. Similarly to the EU-CGMS, China-CGMS is driven by the GIS and crop growth model and consists of three databases: a meteorological database, a soil database and a crop database. It has three levels of functions, including weather monitoring, crop growth modelling and crop yield prediction, each level being supported by the output of the previous one(s). In detail, the three levels are (Huang et al. 2011; Teng et al. 2012):

(1) Weather monitoring, dedicated to the gathering and processing of meteorological data. Weather data are uploaded from the meteorological database and spatially interpolated to a regular 25km x 25km grid for a time series analysis, that provides information for a large area. The weather data may consist of raw data from weather stations or from other sources, such as numerical weather prediction models or satellite estimates.

(2) Crop growth monitoring, which focuses mainly on four major crops: wheat, maize, soybean and rice. The WOFOST crop growth simulation model is used to produce simulated crop information on e.g. biomass and yield, to reveal the climate's influence on crop growth. The WOFOST is a dynamic, explanatory point model and is applied at each Elementary Mapping Unit (EMU), which is the point of intersection between a soil mapping unit, a grid cell and a administrative region. The auxiliary data from the first level and from other databases include meteorological data from the ECMWF (European Centre for Medium-Range Weather Forecasts) and the CMA, soil data from FAO (Food and Agriculture Organization), phenology data from the MoA's department of crop production, crop distribution data from the MoA's RSAC, and other crop parameters and background data from field investigation and literature reviews.

(3) Regional yield prediction is the final level of the CGMS. First, the EMU yield simulations from the second level are aggregated into standard administrative units at various levels (county, province, macro-region) using Equation 2.4 (Supit and Goot 2003).

$$\mathrm{Y_T} = \sum_{i=1}^{n} Y_{Tei}\, A_{ei} C_{ei} / \sum_{i=1}^{n} C_{ei} A_{ei} \qquad \textit{Equation 2.4}$$

where Y_T is the simulated average country yield in year T(kg/ha); Y_{Tei} is the simulated EMU yield in year T(kg/ha); A_{ei} is the EMU area (ha); C_{ei} is the percentage of the EMU area that is suitable for cultivating the specific crop; e is the EMU; and n is the number of EMUs in a given country. The county yield can then be aggregated to the province and macro-region level. The aggregated results are then incorporated into statistical models (regression or scenarios analysis) together with historical yield statistics, to obtain the final prediction of actual regional yields.

Overall, the CGMS was proven to have an accuracy greater than 88 percent for yield forecasting of winter wheat in the North China Plain (Teng et al. 2012). In addition, the output from the CGMS can also be used in combination with RS, meteorological data and historical yield statistics to establish regression or scenario analyses for yield prediction at various administrative levels.

2.1.3 Methodology and practices of the China Meteorological Association

The crop forecasting methodology adopted by the CMA was gradually updated. The statistical regression model based on meteorological data was first applied in the 1980s. In the context of the seventh Five-Year Plan (1986-1990), the CMA built the first crop monitoring system based on meteorological satellite data for the monitoring and yield estimation of winter wheat in the North China Plain, and gradually included other main crops such as maize and rice (Zhao et al. 2007). In the tenth Five-year Plan (2001-2005), the Provincial Agrometeorological Operation and Service System (PAMOS) was established by 10 provincial (municipal or autonomous region) meteorological bureaus under the CMA, including Anhui, Henan, Hebei, Hubei, Guangxi, Beijing and Jiangxi (Wu et al. 2008; WMO 2009). This system is a comprehensive agrometeorological operation and service system integrated with multiple data sources, including weather station observations, historical yield statistics, crop calendars, satellite data and agrometeorological indicators. The various models, such as the meteorological statistical model, the RS model and the crop growth model, are integrated for synthetic crop monitoring and yield forecasting. Since 2006, PAMOS has been recommended for agrometeorological application at various meteorological departments nationwide (He et al. 2009). At the same time, regional crop monitoring and yield forecasting systems have also been developed by meteorological bureaus at provincial (municipal or autonomous region) or county levels for routine meteorological work, such as in Ningxia (Li 2002), Liaoning (Zhang et al. 2003), Henan (Zhang et al. 2004b) and Harbin (Ji et al. 2008).

The meteorological establishments nationwide are operated jointly by the CMA and the relevant Local People's Governments, with the former providing the main leadership. Therefore, meteorological authorities at various levels can develop their own methods or establish their own operational systems for the local meteorological work required in their respective administrative regions. This leads to different methodologies being adopted in the different crop monitoring systems established by each region's various meteorological bureaus. Although it is impossible to enumerate the methodology of every single crop monitoring system, the basic statistical methods can be summarized. Section 2.3.1 below will provide an overview of the basic yield forecasting methodology that is applied in the meteorological statistical system.

2.1.4 Models for meteorology

The basic statistical methods applied in the various meteorological institutions are the following: key meteorological factor model, yield decomposing model, climate suitability model, vegetation index model or crop growth simulation model.

I. Key Meteorological Factor Model:

The key meteorological factor model determines the relationship between crop yield and the key meteorological factors that may critically affect crop yields. The common formula is based on the simple multivariate regression set out in Equation 2.5:

$$Y = a + b_1 \times X_1 + b_2 \times X_2 + b_3 \times X_3 \ , \qquad \textit{Equation 2.5}$$

where Y stands for the yield of the specific crop; X_1, X_2, X_3 refer to the key meteorological factors such as mean temperature, total rainfall and sun hours; a is constant and b_1, b_2, b_3 are the coefficients of each weather factor.

II. Yield Decomposing Model

The yield decomposing model decomposes the yield (Y) into three parts: the potential yield (Y_p), the meteorological yield (Y_m) and the stochastic yield (ΔY). The relevant equation is:

$$Y = Y_p + Y_m + \Delta Y. \qquad \textit{Equation 2.6}$$

The potential yield (Y_p) indicates the optimal crop yield under normal weather conditions, which usually follows an increasing trend due to the improved productivity, breeding and farming technology. Therefore, Y_p is usually described by a function of time with a combination of historical yields. Various methods can be adopted to estimate Y_p, such as the linear, nonlinear, piecewise, linear running averaging, harmonic weighing or exponential smoothing methods. The meteorological yield (Y_m) stands for the effects of weather on yield, and is usually simulated by statistical regression. Typically, the key meteorological factor model (Equation 2.5 above) is used; other statistical methods include stepwise regression, gradual regression, integral regression and the multiple discriminant analysis. The stochastic yield (ΔY) refers to the stochastic error and is often assumed to be negligible in prediction (Wang and He 2009).

III. Climate Suitability Model

Meteorological conditions have a direct impact on crop growth and will ultimately affect the crop yield. In climate suitability model, temperature, rainfall and sunshine hours are considered climate factors that are critical in measuring the impact of the climate on crop growth at various periods. By integrating three climate factors, a synthetic Climate Suitability Index (CSI) can be developed to estimate crop yield, by means of the following procedures (Liu et al. 2008; Wei et al. 2009; Yi et al. 2010).

First, the impact of each climate factor is described by one suitability function based on fuzzy set theory:

$$T(t_i) = \frac{(t_i - t_{li}) \times (t_{hi} - t_i)^B}{(t_o - t_{li}) \times (t_{hi} - t_o)^B}, \qquad \textit{Equation 2.7}$$

$$B = \frac{t_{hi} - t_{oi}}{t_{oi} - t_{li}}, \qquad \textit{Equation 2.8}$$

where $T(t_i)$ refers to the average temperature suitability for dekad i (ten days); t_i stands for the average temperature for dekad i; and t_{li}, t_{hi} and t_{oi} respectively indicate the lowest, highest and optimal temperature in dekad i.

$$R(r_i) = \begin{cases} r_i / r_{0i} & r_{ij} < r_{0j} \\ r_{0i} / r_i & r_{ij} \geq r_{0j} \end{cases}, \qquad \text{Equation 2.9}$$

where $R(r_i)$ refers to the average rainfall suitability for dekad i; r_i stands for the average rainfall for dekad i; and r_{oi} indicates crop water demand (mm) for dekad i.

$$S(s_i) = \begin{cases} e^{-[(s_i - s_{0i})/b]^2} & s_i < s_0 \\ 1 & s_i \geq s_0 \end{cases}, \qquad \text{Equation 2.10}$$

where $S(s_i)$ refers to the suitability of average daily sunshine hours for dekad i; s_i stands for the average daily sunshine hours for dekad i; s_oi denotes the sunshine hours threshold in dekad i, which is commonly set to 70 percent of the total potential sunshine duration; and b is a constant that is calibrated according to the region and crop growing period.

The dekad is the minimum time step for meteorological measurements. However, in crop monitoring and yield estimation, the commonly used time step is the crop growing stage. Therefore, the dekadal indicators should be weighed and aggregated to different growing stages or a whole period, considering that the climate impact on crop yield changes over time. In this case, the simple regression is applied between annual historical yields and each dekadal suitability indicator to obtain the Correlation Coefficient (CC) of each indicator (CC_{ti}, CC_{ri}, CC_{si}) for each dekad. For a given dekad, the absolute value of its corresponding CC is used to calculate its weighing factor for each indicator (W_{ti},W_{ri},W_{si}), according to the equations given below:

$$W_{ti} = \frac{|CC_{ti}|}{\sum_{i=m1}^{m2} |CC_{ti}|}; \qquad \text{Equation 2.11}$$

$$W_{ri} = \frac{|CC_{ri}|}{\sum_{i=m1}^{m2} |CC_{ri}|}; \qquad \text{Equation 2.12}$$

$$W_{si} = \frac{|CC_{si}|}{\sum_{i=m1}^{m2} |CC_{si}|}, \qquad \text{Equation 2.13}$$

where W_{ti}, W_{ri} and W_{si} refer to the weighting factors of temperature, rainfall and sunshine hours at dekad i; CC_{ti}, CC_{ri} and CC_{si} stand, respectively, for the CC between the yield and the suitability indicator of temperature, rainfall and sunshine hours at dekad i; $m1$ and $m2$ respectively denote the beginning and ending dekad of growing period m.

By multiplying the weighting factor, the dekadal suitability indicators can finally be aggregated to a given growing period or to the whole growing period (Equations 2.14 to 2.16). On the basis of the integration of three climate factors (temperature, rainfall and sun hour), the CSI may be established with Equation 2.17.

$$T_m(t) = \sum_{i=m1}^{m2} W_{ti} T(t_i); \quad \text{Equation 2.14}$$

$$R_m(r) = \sum_{i=m1}^{m2} W_{ri} R(r_i); \quad \text{Equation 2.15}$$

$$S_m(s) = \sum_{i=m1}^{m2} W_{si} S(s_i); \quad \text{Equation 2.16}$$

$$CSI_m = \sqrt[3]{T_m(t) \times R_m(r) \times S_m(s)}\ , \quad \text{Equation 2.17}$$

where, T_m (t), R_m (r), S_m (s) and CSI_m respectively denote the indicators of temperature suitability, rainfall suitability, sun hour suitability and climate suitability for growing period m; while $m1$ and $m2$ respectively stand for the start and ending dekad of growing period m. When $m1=1$ and $m2=n$ (number of dekad with whole growing period), T_m (t), R_m (r), S_m (s) and CSI_m refer to the suitability indices over the whole growing period.

Finally, the CSI can be used to predict yield (Y) in multiple ways:

(1) Simple regression between the CSI over the crop's whole growing period and the historical yield:

$$Y = a + b \times CSI \quad \textit{Equation 2.18}$$

(2) Substituted into the key meteorological factor model Equation 2.5, using the CSI at different crop growing periods (CSI_{m1}, CSI_{m2}, CSI_{m3}):

$$Y = a + b_1 \times CSI_{m1} + b_2 \times CSI_{m2} + b_3 \times CSI_{m3} \quad \textit{Equation 2.19}$$

(3) Substituted into the yield decomposing model Equation 2.6 for term Y_m:

$$Y = Y_p + b \times CSI + \Delta Y \quad \textit{Equation 2.20}$$

IV. Vegetation index model

The vegetation index is developed on the basis of the plant's spectral characteristics (reflection and abstraction at different spectral domains) using RS data. As a good indicator of plant vigour and growing conditions, it can also be used for crop yield estimation. Various vegetation indices have been developed, and the most commonly used in yield forecasting are the NDVI, followed by the EVI (Enhanced Vegetation Index), the RVI (Ratio Vegetation Index) and the GVI (Greenness Vegetation Index). In addition, the LAI (Leaf Area Index) and the NPP (Net Primary Production), which are both closely related to and can be derived from the NDVI, are also used in yield estimation. The general formula is based on the linear relationship shown in Equation 2.21.

In addition, the vegetation index can also be combined with meteorological factors to yield a better prediction in Equation 2.22 (Li et al. 2012).

$$Y = a + b \times VI \qquad \text{Equation 2.21}$$

$$Y = a + b \times VI + b_1 \times X_1 + b_2 \times X_2 , \qquad \text{Equation 2.22}$$

where Y indicates the yield of the specific crop; VI denotes the vegetation index, such as NDVI, LAI or NPP; X_1 and X_2 stand for different meteorological factors, such as temperature and rainfall; b, b_1 and b_2 are the coefficients of the vegetation index and meteorological factors; and a is constant.

V. Crop growth simulation model

Due to the diffusion of nationwide meteorological stations and the availability of hourly updates for meteorological measurements, the crop growth simulation model has also gained widespread application among regional meteorological bureaus in compiling local crop forecasts. The most commonly used model includes WOFOST and CROPWAT for maize yield forecasts (Chen et al. 2007; Kang et al. 2010), DSSAT for wheat forecasts (Yang et al. 2009b) and ORYZA2000 for rice forecasts (Liu et al. 2009). Advanced agricultural simulation systems such as APSIM (Agricultural Production Systems sIMulator) have also been applied in predicting wheat yield in the North China Plain (Li et al. 2009). However, due to the complexity of the crop growth model and the high volume of input data required, currently this model is still at a research stage, and not yet fit for operational application. Combined with satellite data, crop growth models have gradually improved and have given rise to a new trend in meteorological crop forecast systems.

2.2. Relevant practices for data collection

As mentioned in the Sections above, traditional statistical methods (complete reporting system and sample surveys) are suitable for crop production estimates, while RS systems may be used in crop yield forecasting.

With reference to the traditional statistical methods, the complete reporting system is based on the hierarchical administrative structure: the estimates and report are provided from the basic village level to the township level, are then summarized at county and at province levels, and are finally aggregated into national totals. The sample survey, instead, is based on administrative institutions at three levels: the NBS's Division of Agricultural Survey is in charge of the national rural socioeconomic sample survey at national scale. At provincial level, each of the NBS survey offices established in 31 provinces (autonomous regions and municipalities) manage the crop sampling survey for their own province, and then submit the final estimates to the NBS on a regular basis. The NBS survey offices at county level are responsible for conducting surveys in all sample villages (Pan et al. 2010). The sample villages are identified by the provincial survey office, using a PPS method, while the systematic sampling method is used by staff members and assistant interviewers from county survey offices to select sample fields within the sample villages with equal probability (Zhao and Zhou 2010). A similar approach is adopted for the sample survey conducted by the MoA.

Both the NBS and the MoA adopt the traditional statistical method combined with RS

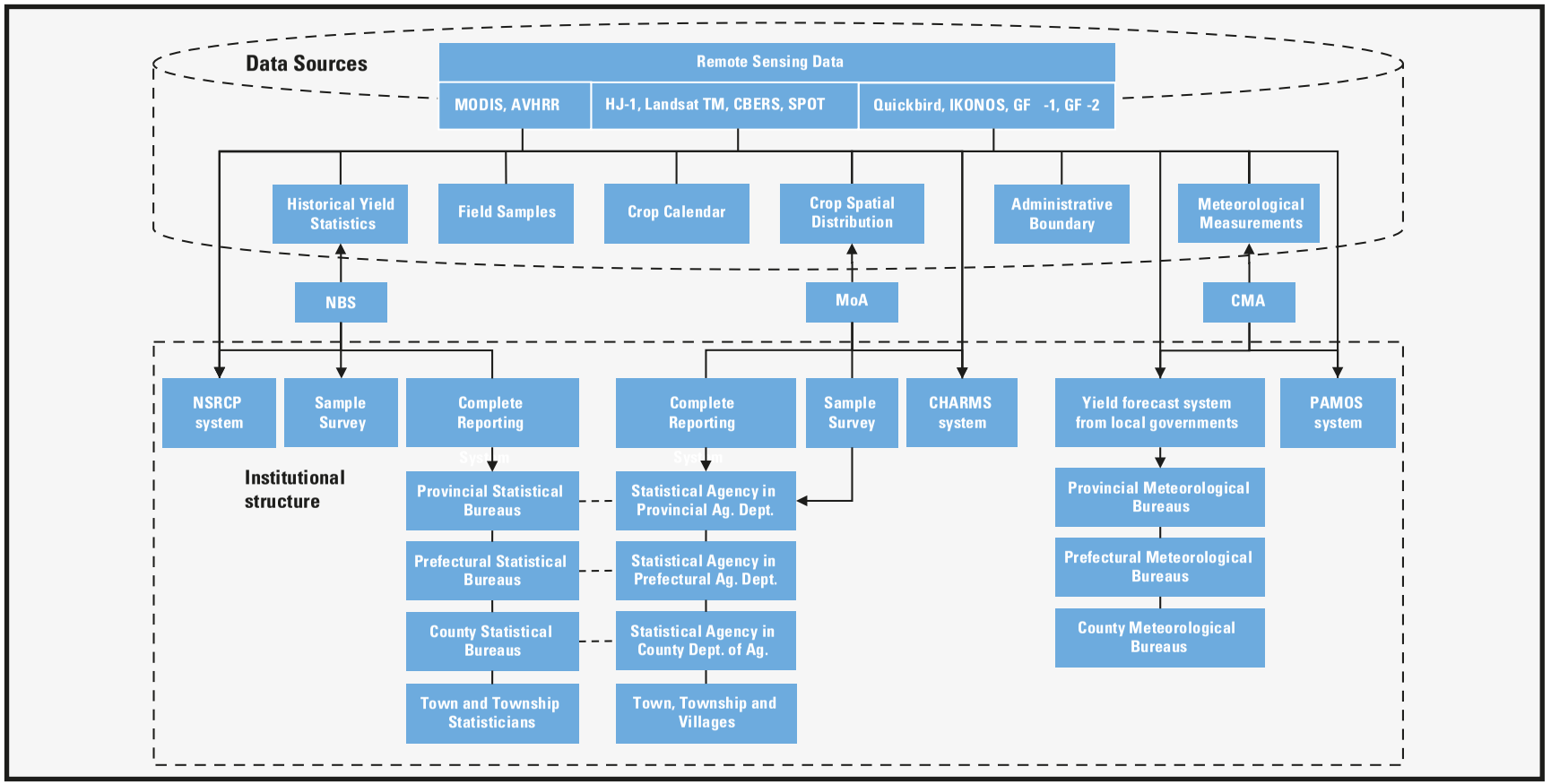
systems (the NBS's NSRCP and the MoA's CHARMS) for the crop yield forecast, while the CMA relies mainly on the RS systems (PAMOS and regional systems) within meteorological bureaus to provide crop forecast.

For crop forecasts, although different RS systems are adopted in different organizations, they generally share the same basic data sources. Figure 2.3 below also illustrates the data flow and data sharing among the NSRCP/NBS, CHARMS/MoA and PAMOS/CMA yield forecasting systems. The basic common data sources include historical yield statistics accessible from the NBS, crop spatial distribution data available from the MoA, meteorological measurements obtained from the CMA, field sampling conducted by each organization, multi-source and multi-resolution RS data and other auxiliary information such as crop calendars and administrative boundaries. The basic data sets are shared among different organizations through publicly-available resources, collaborated programs and dedicated networks.

Among the basic inputs, RS data are important components of each organization's RS yield forecasting system (NSRCP in the NBS, CHARMS in the MoA and PAMOS and regional systems in the CMA). RS imagery is also applied when designing and updating the sampling frame and when selecting sampling counties in the NBS system. The more commonly used multi-source and multi-scale RS data include those from MODIS, AVHRR (coarse resolution: 250m-1000m), Landsat TM, CBERS, SPOT (medium resolution: 20m-30m) and Quickbird, IKONOS, GF-1, GF-2 (high resolution: 0.6m-8m). These data are widely adopted for three main reasons: they present long time series and are freely available (e.g. MODIS, AVHRR and Landsat TM), they use domestic satellites that have an easy-to-use or dedicated supply channel (see HJ-1, CEBERS, GF-1 and GF-2), and they are of high quality and have a high spatial resolution (e.g. SPOT, Quickbird and IKONOS). The ample national funds made available to each official organization constitute a solid financial foundation for the purchase and processing of RS data.

FIGURE 2.3

Data sources and institutional structure of official yield forecasting organizations



The official providers of crop yield forecasts in China are the NBS, the MoA and the CMA. Both the NBS and the MoA adopt the traditional statistical method combined with remote sensing, while the CMA relies mainly on remote sensing.

2.3. Practices for data sharing and analysis, harmonization, and integration

As mentioned in Section 1.3 above, the crop yield forecasts computed by the NBS and the MoA are for internal use only.

On the other hand, the CMA's forecasts are released in various ways.

Internal dissemination: two national consulting conferences are hosted by the CMA every year (in mid-May and in late August) to assess the national yield of summer crops and autumn crops; the conferences are attended by representatives of all provincial meteorological bureaus and other official departments and institutions, including the MoA, the NBS, SAG, the MCA and the CAS.

External dissemination: the critical agrometeorological updates are directly reported to the State Council, the Rural Work Leading Group of the CPC's Central Committee, the NDRC, the MoF, the MoA and other related government departments; the crop forecasts may be updated in the periodical Agro-Meteorological Bulletins, with ten-day, monthly, seasonal or annual time intervals. During the important growing periods for specific crops, special topic reports are issued to enable the dynamic monitoring of crop conditions and the yield prospect.

TABLE 2.3
Timeline of releases from the China Meteorological Administration

I. Crop Production Consulting Conference		
ID	**Month**	**Content**
C_C1	Mid-May	Assessment on national production of summer crops
C_C2	Late-August	Assessment on national production of autumn crops and the crop production of whole year
II. Yield Variation Forecast (Wang and He 2009)		
ID	**Month**	**Content**
C_V1	April	Estimated yield variation of winter wheat, rapeseed
C_V2	June	Estimated yield variation of early rice
C_V3	July	Estimated yield variation of mid-rice, maize, cotton and soybean
C_V4	October	Estimated yield variation of late rice
III. Yield Forecasts (Wang and He 2009)		
ID	**Month**	**Content**
C_Y1	May	Yield forecast of winter wheat, rapeseed
C_Y2	July	Yield forecast of early rice
C_Y3	August	Yield forecast of mid-rice, maize, cotton and soybean
C_Y4	October	Yield forecast of late rice

2.4. Human, financial and technical infrastructure

As the main provider of national statistical data, the NBS establishes survey offices in each province (autonomous regions and municipalities), as well as a survey team in each city (prefectures, autonomous prefectures and leagues) and in one-third of the counties (cities at county level, districts and banners). These all serve as the NBS' agent organs and are responsible mainly for the surveys (essentially sampling surveys) of key statistical data required by the NBS (Brazil et al. 2014).

The MoA has a similar human and technical infrastructure.

The CMA relies on three features in providing crop yield forecasting services: an integrated agrometeorological observation network, diverse crop forecasting technologies and a well-organized consulting service system. Currently, the CMA has established 36,100 automatic meteorological stations, 653 agrometeorological observation stations, 70 agrometeorological experimental stations, and 2,124 soil moisture automatic observation stations (CMA 2015) – a solid foundation for taking the field measurements of meteorological variables. To date, China has launched 12 meteorological satellites; of these, satellites FY1 and FY-3A have played an important role in agrometeorological monitoring and crop yield forecasting. Together with other domestic and international satellite data from satellites including EOS/MODIS, NOAA/AVHRR, Landsat TM, CBERS, SPOT, Quickbird, IKONOS, GF-1 and GF-2, multi-source and multi-scale RS has come to perform a major part in crop monitoring and forecasting in the CMA. By incorporating space-based, airborne and ground-based observations, the CMA has established an integrated meteorological observing system that can sustainably provide support to agrometeorological services.

2.5. Institutional structure and sustainability

The national institutions' system of crop yield forecasting is well-established and sustainable. Furthermore, although the official organizations (NBS, MoA and CMA) conduct crop forecasts separately, they all directly report to the State Council.

2.6. Innovation and integration with regional- and global-level initiatives

As mentioned in Section 2.1.2.1 above, China's CGMS implemented by the MoA is an adaptation of a broader system developed for European countries by the JRC-MARS[17] unit. In 2010, the CGMS was built into CHARMS by adjusting and localizing the database, crop parameters and monitoring scale to take China's conditions into account. Similar to EU-CGMS, China-CGMS is driven by the GIS and crop growth model and consists of three databases: a meteorological database, a soil database and a crop database.

[17] This is the Monitoring of Agriculture with Remote Sensing unit of the European Union's Joint Research Centre.

3. Linking up with crop production forecasts: the practices followed by China's national official sources

In China, grain production is calculated by multiplying the yield with the sown area (or planting area). This Section describes the crop area estimation methods of the NBS, the MoA and the CMA.

3.1. Which area data is used? The methodology applied

3.1.1. Area estimation in the NBS

In the NBS, area estimation is traditionally based on the sample survey of county interviewers. In accordance with the planting season, the surveys of main crop area are carried out at three times: during the autumn-winter planting season, the spring planting season and the summer planting season. The representative sample villages are determined by the NBS's provincial survey office, by means of a PPS sampling method. Next, county interviewers travel directly to the sample site to compile records of agricultural households and register the fields. After the sowing season, the county interviewers collect, check and verify the records to obtain the planting area. The area data are then reported to the provincial office, where a self-weighted method is used to estimate the planting area of the main grains at provincial level. Finally, the NBS head office will check the area data from each province and add it the national area for the relevant grain (China 2011).

In 2006, the NBS developed the NSRCP, of which the Cropland Acreage Estimation by Using Remote Sensing and Sample Survey (CAERSS) is a core component for area estimation based on the area sampling frame and RS technology. Pilot applications of the CAERSS have been conducted in five provinces including Liaoning, Jilin, Henan, Jiangsu and Hubei. Generally, CAERSS envisages five steps for generating the planting area estimation, which largely follow the descriptions given by Pan et al. (2012) and Wang and Wei (2014):

Step 1: Selection of the Primary Sampling Unit (PSU). For a given province, the 3km x 3km grids are overlaid on its administration boundary. Then, the village crop data from the second national agricultural census, current or recent high-resolution RS images, and data from the second national land survey are used to determine the crop coverage and cultivated land within the grids. After eliminating the uncultivated land, the grids with arable land and that are covered by RS imagery are selected as PSUs for the sampling frame.

Step 2: Extraction of crop information. Within each PSU, crop information – including the arable land area, the planting area of different crops and crop distribution – are extracted from historical and real-time RS imagery, by means of a set of comprehensive classification methods.

Step 3: Stratification and Sample Selection. A cluster analysis is adopted to classify the PSUs into different strata, each of which contains homogenous crops. Then, a two-stage sample is applied for each stratum. In the first stage, a PPS (probability proportional to arable area) method is used to select the PSUs. In the second, a simple random sampling

method is applied to choose three to five sample plots within each sample PSU, with the help of high-resolution imagery. Considering the crop planting area of different provinces, the sample plot area is set to two hectares (30 "mu") in Jiangsu and Hubei, and to five hectares (75 "mu") for Liaoning, Henan and Jinlin.

Step 4: Conduction of field survey. The field survey is conducted at two times. The sample plot registration is first carried out using GPS and PDAs to locate and make records of the sample plots. Then, for the purposes of area estimation, during the crop planting season, the crop planting area is measured with PDAs and other tools, such the ground truth data.

Step 5: Area estimation. Based on the field area survey of sample plots within each sample PSU, the area of certain crops at county level can be computed by means of a small area statistical model, or similarly to the provincial area estimation, using Equation 3.1 below (Wang and Wei 2014):

$$A = \sum_{i=1}^{m} \sum_{j=1}^{n_i} a_{ij} w_{ij} w_i, \qquad \textit{Equation 3.1}$$

where A stands for the province's estimated sown area; m denotes the total number of sample PSUs within the province, and n denotes the total number of sample plots within each sample PSU; x_{ij} indicates the survey sown area of sample plot j within sample PSU i; w_{ij} indicates the weighting factor from sample plot j to sample PSU i; and w_i indicates the weighting factor from sample PSU i to the province.

Compared to traditional area sampling surveys, the CAERSS brings improvements in terms of objectiveness, timeliness and cost efficiency. However, the CAERSS has not been extended for area estimation at national level due to problems in the quality of the basic statistical information, the acquisition capacity of RS data, the standardization of data acquisition and processing, RS crop identification and measurement assessment and validation. Currently, the NBS is working on these issues and aims to establish a crop area and RS system in the near future.

3.1.2. Area estimation in the MoA

The CHARMS, developed by the RSAC, is the MoA's current operational system for crop monitoring and crop forecasting. In CHARMS, the crop planting area estimation is achieved mainly by means of two methods: stratified sampling using RS and ground random sampling using GPS. The former is the method of major application, and the latter is a supplement. The brief introduction of the two methods set out below essentially follows that given by Wu and Sun (2008).

I. The Stratified Sampling Method

Crop area estimation using the Stratified Sampling Method (SSM) can be divided into four steps:

Step 1: Identification of the cropping zone. Although many crops are planted in China, the RSAC focuses its attention on the main crops, including wheat, maize, soybean, rice and

cotton. These are mainly concentrated in about 15 provinces. Therefore, the cropping zone of each main crop is determined, to enable focused study and further analysis.

Step 2: Selection of the sample unit. The sampling unit is based on the county administrative boundaries within the main producing provinces and a relief map with a scale of 1:50,000 or 1:25,000. According to cropping zones, the stratification is first applied with a maximum of six layers, using two methods, namely Frequency Accumulation Means (FAM) and Systematic Clustering Means (SCM), in which the multi-year statistical data from local governments and the latest land use data in vector format serve as background data. A certain number of units is then selected from each layer according to the method proposed by Chen et al. (2000).

Step 3: Interpretation of crop information. Crop identification using RS images of sample areas constitutes the core of the SSM. The RS images that cover the sample units and were acquired early in the crop planting season are collected. Then, the crop information – including crop type, crop area and crop distribution – is interpreted for each sample unit from the RS images. The area variation rate is also computed from RS images for two continuous years.

Step 4: Area estimation. Based on the results in Step 3, the total planting area can be estimated using Equation 3.2 (Wu and Sun 2008).

$$A = \sum_{i=1}^{L} \sum_{j=1}^{N_i} \left(\frac{1}{n_i} \sum_{j=0}^{n_i} a_{ij} \right), \qquad \textit{Equation 3.2}$$

where A indicates the total area; L indicates the total number of layers; N_i denotes the total number of units in layer i; n_i denotes the total amount of samples units in layer i; and a_{ij} denotes the crop area in unit j of layer i.

II. Ground Random Sampling

The Ground Random Sampling (GRS) method is based on field surveys used to locate polygons (the sampling units) on farmland using GPS. The polygon is usually set to an area of approximately 25 hectares, with boundaries composed mainly of natural borders, such as roads. Then, a GIS is used to compute the crop proportion and crop area with the spatial information obtained from the GPS. As an independent method, GRS can provide validation and reference to the interpretation of RS images. At the same time, it can serve as a complement to SSM, especially when RS images are unavailable for this latter method (Wu and Sun 2008).

With the support of ground truth data from over 6,000 nationwide in situ rectangles (500m x 500m) and periodic field campaigns, the combination of SSM and GRS was adopted in CHARMS and then successfully applied to main crop area monitoring for many years at national level (Chen et al. 2011). In addition, CHARMS also adopts the MODIS NDVI time-series to automatically identify the planting area of four major crops (spring wheat, spring maize, soybean and rice) in Northeastern China (Huang et al. 2012b). Although RS technology greatly improves the MoA's efficiency for area estimates, it also leads to another problem: the accuracy of estimation largely depends on the quality of the RS data, the

accuracy of the RS indicator and the accuracy of crop interpretation based on RS images. These problems and technical difficulties are expected to be solved in the future with the development of novel methodologies and the advance of spatial technology.

3.1.3. Area estimation in the CMA

For area estimation, the CMA relies mainly on RS technology. Its general idea is to take advantage of crop-distinctive spectral features in crucial growing periods, to identify the target crop and extract area information on the basis of different classification methods and RS data. The overall procedure can be broken down into the following four steps.

Step 1: Data preparation. In the CMA, multi-sale and multitemporal RS imagery serves as the basis for area estimation. The commonly used RS data include those from MODIS (coarse resolution: 250m-500m), Landsat TM, SPOT, HJ-1 (medium resolution: 20m-30m), ALOS and IKONOS (high resolution: 1m-10m). The operations of data ordering, downloading and pre-processing (such as projection transformation, geometric correction, image mosaicking and noise smoothing) are necessary. In addition, the administrative boundaries, land use and land cover, the crop distribution map and the crop calendar are also required as auxiliary data; the ground truth data are essential for validation of area estimation.

Step 2: Selection of crop indicator and key growing period for crop extraction. Different crops may present different spectral features at different growing stages. Therefore, the spectral reflectance and vegetation index that is a combination of different spectral bands are both good indicators for crop identification. The commonly used vegetation indices include the NDVI, the EVI and the Land Surface Water Index (LSWI). Based on time-series RS data, these indices and the individual spectral bands are plotted against crop growing periods; then, the crucial periods and optimal indicators for distinguishing the target crop from other land objects can be determined. For example, Yu et al. (2011 and 2013) revealed that the transplanting and booting stages are both suitable to identify rice, and that the LSWI performs better than the NDVI and the EVI in rice identification at transplanting period.

Step 3: Classification and crop extraction. This is the core of area estimation. Based on vegetation indices, various classification methods, including Supervised (Han et al. 2006) and Unsupervised Classification (Yu et al. 2013), the Decision Tree (Feng et al. 2011) and the combining method (Ding et al. 2012) have been experimented in crop extraction. For example, Feng et al. (2011) proposed the following rules (Equations 3.3 to 3.5) for rice identification in Northeast China, based on decision tree classification with MODIS data.

$$-0.05 < LSWI_t < 0.35; \qquad \textit{Equation 3.3}$$

$$0 < NDVI_t - EVI_t < 0.16; \qquad \textit{Equation 3.4}$$

$$NDVI_h - NDVI_t > 0.46; \qquad \textit{Equation 3.5}$$

where t indicates the transplanting stage of rice and h indicates the heading stage of rice.

Step 4: Area calculation. According to the RS data used for classification, there are two ways to determine final area estimation.

1) If the coarse resolution data (MODIS) are used directly for the crop classification of a large area, the final area of the target crop can be calculated by means of Equation 3.6:

$$A = \sum_{i=1}^{n} a_i, \qquad \textit{Equation 3.6}$$

where A stands for the area of target crop in a given large region; a_i stands for the area of each pixel i in the coarse-resolution image; and n stands for the total number of pixels classified as target crop. This method may be used for area estimation in large areas with homogeneous crop cover.

2) Considering China's fragmented cultivation area and the problem of mixed pixels in coarse-resolution imagery, the crop area is not calculated directly from the coarse resolution imagery. Instead, the medium-resolution data (such as that from Landsat TM, SPOT, HJ-1) are used first for regional classification and then combined with a linear decomposition of mixed pixels of time-series coarse imagery (MODIS); the crop area is further computed through scale transformation. Xu et al. (2007) adopted this method to obtain the winter wheat area in Henan Province with an accuracy of 95 percent compared to national official statistics. Equation 3.7 shows the basic formula for linear decomposition of mixed pixels, and Equation 3.8 shows the final area calculation based on the linear decomposition method:

$$R(j) = \sum_{i=1}^{n} r(i) \times p(i,j); \qquad \textit{Equation 3.7}$$

$$A(i) = \sum_{j=1}^{m} a(j) \times p(i,j); \qquad \textit{Equation 3.8}$$

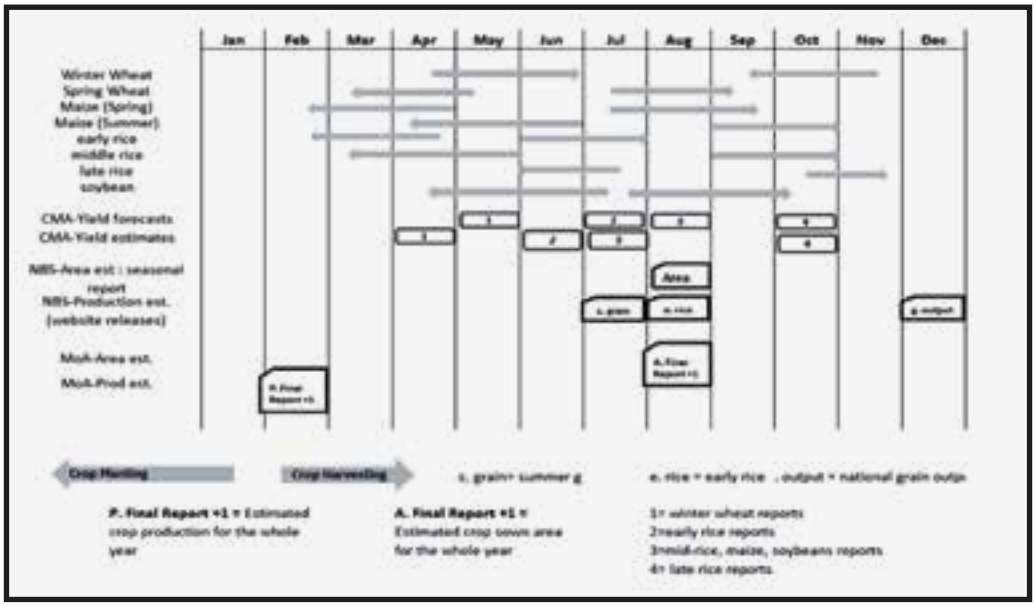
where $R(j)$ denotes the mixed spectral reflectance of pixel j in a coarse resolution image; n denotes the total number of object types included in pixel j of a coarse-resolution image; $r(i)$ denotes the pure reflectance of object i in a medium-resolution image; $p(i, j)$ denotes the area proportion of object i in pixel j that can be computed from the classification result of a medium-resolution image; $A(i)$ indicates the final area of target crop i in the large region in question; m indicates the total number of coarse pixels containing the target crop; and $a(j, i)$ indicates the area of each pixel j in a coarse-resolution image.

3.2. Release calendars: punctuality and timeliness

Official national organizations in China do not publish crop production forecasts. These data are produced for internal use only.

Table 2.4 provides a complete description of the release frequency of yield forecasts and estimates, and acreage and production estimates in China, together with the main crops' planting and harvesting calendars. For a more detailed comparison of the crop reporting dates from the NBS, the MoA and the CMA with the crop calendar, see Table B2.3, Annex B2.1.

TABLE 2.4
Crop calendar and release frequency of crop forecasts and estimates



3.3. Human, financial and technical infrastructure

For the human, financial and technical infrastructure of China's system for crop yield forecasting and crop area estimation, see Section 2.4 above.

3.4. Institutional structure and sustainability

The national institutions' system for crop production forecasting is well-established and sustainable. Furthermore, as mentioned above, although the official organizations (NBS, MoA and CMA) conduct crop forecasts separately, they all directly report to the State Council.

3

Crop Yield Forecasting in Morocco

Michele Bernardi[1]

1. Crop yield forecasts data for Morocco

1.1. Brief description

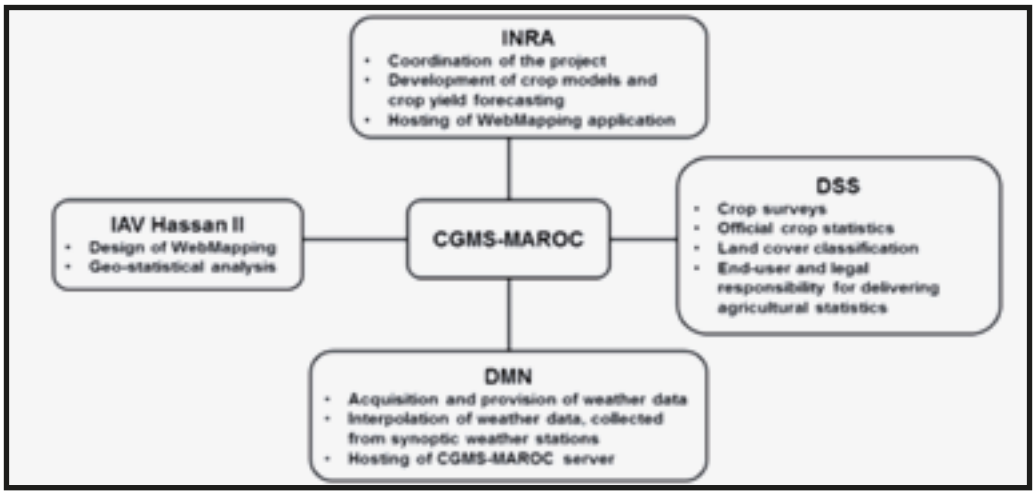
Crop monitoring and yield forecasting is an essential component of climate risk management in agriculture in Morocco, as the agricultural sector is one of the economy's main areas and presents a high annual variability. Crop yield forecasts are elaborated by the Department of Strategy and Statistics of the Ministry of Agriculture (DSS[2]), on the basis of a qualitative survey and of "subjective yields"; this, in turn, is an assessment carried out in relation to a sample of plots. In a more complete approach, the Crop Growth Monitoring System – Morocco (CGMS-MAROC[3]) is the national system for crop monitoring and for the agrometeorological yield forecasting of cereal crops. It was initiated by the National Institute for Agricultural Research (INRA[4]) within the framework of the E-AGRI[5] project. As illustrated in Figure 1 below, CGMS-MAROC is coordinated by the INRA, through a formal consortium with the National Department of Meteorology (DMN[6]), the DSS and the Institut Agronomique et Vétérinaire Hassan II (IAV[7]). Its development was made possible with the support of a technological collaboration with international research institutions, namely the Flemish

1 Independent Consultant.
2 DSS: http://www.agriculture.gov.ma/pages/statistiques-agricoles
3 CGMS-MAROC: http://www.cgms-maroc.ma/
4 INRA: http://www.inra.org.ma/accueil1.asp?codelangue=23&po=2
5 E-AGRI: http://www.e-agri.info/
6 DMN: http://www.marocmeteo.ma/
7 IAV: http://www.iav.ac.ma/

Institute for Research and Technology (VITO[8]), the Research Centre of the European Union (EU-JRC[9]), the Research Institute of the University of Wageningen (ALTERRA[10]) and the University of Milan (UNIMI[11]). CGMS-MAROC is the first operational system for the crop monitoring and the agro-meteorological yield forecasting of cereal crops in Morocco, as well as the first of these systems to be institutionalized through a strategic partnership to enable its development and sustainability.

Similarly to the B-CGMS in Belgium, the concept behind the CGMS-MAROC is to provide an adapted and improved version of the CGMS[12] implemented by the MARS Unit of the Joint Research Center (JRC-MARS[13]). As mentioned in Annex B1 relating to the Belgium case study, in 1992, the JRC developed a crop yield forecasting system, which it maintains to this day and which provides timely forecasts for crop production – including biofuel crops – for Europe and other strategic areas (EU Member States, the Maghreb region, the European part of Russia, Ukraine, and Belarus). The MCYFS[14] monitors crop vegetation growth (for cereals, oil seed crops, protein crops, sugar beet, potatoes, pastures, rice), including the short-term effects of meteorological events upon crop production. The MCYFS also provides seasonal yield forecasts for key European crops (wheat, maize, etc.).

FIGURE 3.1
The CGMS-MAROC's institutional structure



Source: Balaghi et al. 2013

The CGSM-MAROC is coordinated by the INRA through a formal consortium with the DSS, the DMN and the IAV, each institution having its own functions and responsibilities. This partnership ensures the system's efficiency and sustainability.

8 VITO: https://vito.be/en
9 EU-JRC: https://ec.europa.eu/jrc/
10 ALTERRA: http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/Alterra.htm
11 UNIMI: http://www.unimi.it/
12 The Crop Growth Monitoring System (CGMS) is the core of the MARS Crop Yield Forecast System (MCYFS) currently used in forecasting activities in Europe by AGRI4CAST action. http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/Crop-Growth-Monitoring-System-CGMS
13 JRC-MARS: http://mars.jrc.ec.europa.eu/mars/About-us/The-MARS-Unit
14 MCYFS; http://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Main_Page

1.2. Inventory of forecasts available, by source

1.2.1. Official national sources

Five official national sources release forecasts and estimates of cereal crop yields in Morocco:

- the CGMS-MAROC generates yield forecasts for soft wheat, durum wheat and barley;
- the Royal Centre for Remote Sensing (CRTS[15]) elaborates a Total cereal production forecast;
- the Bank Al Maghrib (BAM[16]) provides a Total cereal production forecast;
- the DSS generates a Cereal production estimate; and
- the High Commission for Planning (HCP[17]) of the Directorate of Statistics provides a Cereal production estimate.

The DSS is in charge of national agricultural surveys and statistics since 1975.

The methodologies used by the DSS, the HCP, the CRTS and BAM are described in Section 3 below; however, the documents produced by the HCP, the CRTS and BAM are not available to the public, as crop estimates are reserved for internal use.

1.2.2. Non-official national sources

For Morocco, there are no other national sources. However, crop monitoring and yield forecasting activities for the Maghreb countries (including Morocco) are also performed by the EU'S JRC-MARS Unit.

1.2.3. Regional and global sources

The Cadi Ayyad University[18] is part of Morocco's JECAM[19] (GEO Joint Experiment for Crop Assessment and Monitoring) project on crop identification and crop area estimates. The project has the following objectives:

- Mapping Agricultural Areas
  - Land Cover Mapping: on an annual basis
  - Cropped Land Mapping: on an annual basis
- Estimating Crop Areas: Statistical Units – plots
- Estimation of Biophysical Variables
  - Fraction cover
  - Crop coefficients (FAO56)
  - Biomass

[15] CRTS: http://www.crts.gov.ma/Royal%20Centre%20for%20Remote%20Sensing
[16] BAM: http://www.bkam.ma/
[17] HCP: http://www.hcp.ma/
[18] Cadi Ayyad University: http://www.uca.ma/site/
[19] JECAM Morocco: http://www.jecam.org/?/project-overview/morocco-tensift-watershed

    - Yield
- Phenological Events: Crop Stress
    - Integration of the EO-Derived Information into Crop/Agro-Met Models
    - Vegetation fraction cover
    - Crop coefficients (FAO56)
    - Crop Stress (thermal images)
- Forecasting Agricultural Variables from Crop/Agro-Met Models
    - Water consumption
    - Crop yield.

1.3. Release calendars: punctuality and timeliness

The DSS provides crop yield estimates[20] on the basis of a survey conducted in two phases: a qualitative survey performed in April, and another one carried out from May to September, on the basis of "subjective yields". These, in turn, are assessments that are executed in a sample of plots. As mentioned above, the HCP and BAM do not release the documents that they produce, as these are for internal use only. The CRTS provides crop acreage estimates in the framework of a new project entitled "Al Majal Operation" (FAO 2009), on the basis of updated images at high spatial resolutions.

The establishment of the CGMS-MAROC has enabled improvements in the quality and timeliness of statistical data. Originally, the bulletin was published in collaboration with the JRC-MARS Unit; today, it is published independently, in collaboration with the three national partners (see Figures B3.1 and B3.2, Annex B3.1). The CGMS-MAROC currently releases crop yield forecasts for cereals at national level, and publishes them in its agrometeorological bulletin[21] and on its website. The CGMS-MAROC performs data processing at 10-day (dekad) temporal intervals.

The monthly EU-MARS bulletins[22], released from January to December, provide yield forecasts for main cereals at national level for the 28 EU Member States, Turkey, Ukraine, the Russian Federation, Belarus and the Maghreb countries, including Morocco.

1.4. How do these different forecasts compare? Purpose, coverage, scale and harmonization issues, accuracy

The CGMS-MAROC provides crop yield forecasts at the same administrative levels as those of the DSS. As historical crop statistics, the data are coherent with those provided by the DSS, and are used for the statistical model. Section 2 below presents a detailed description of the crop yield forecasting methodology applied by the CGMS-MAROC. The outputs of the CGMS-MAROC and the EU-CGMS are very similar.

[20] DSS report: http://www.agriculture.gov.ma/rapports-statistiques
[21] CGMS-MAROC bulletin: http://www.inra.ma/docs.asp?codedocs=139&codelangue=23
[22] EU-MARS bulletin: ftp://mars.jrc.ec.europa.eu/Bulletin/Europe/

Table 3.1 compares crop yield forecasts at national level for the main crops, as released by the two different systems.

TABLE 3.1
Crop yield forecasts (t/ha) at national level for the 2012-2013 cropping season, as released by the CGMS-MAROC and the EU-CGMS, on the basis of their respective methodologies

	Yield (t/ha)		
System	**Soft wheat**	**Durum wheat**	**Barley**
CGMS_MAROC	1.93	1.92	1.40
EU-CGMS	1.89	1.85	1.26

Dates of release:
CGMS-MAROC: 17 April 2013
EU-CGMS: 21 May 2013

The CGMS-MAROC releases provisional forecasts each year during the month of April, and constantly revises them as the season progresses.

Tables 3.2 and 3.3 below provide examples of this revision process, illustrating how the provisional forecasts released on 10 April 2012 (Table 3.2) have been corrected in the final forecasts for the 2012-2013 season (Table 3.3).

TABLE 3.2
Provisional forecasts as at 10 April 2012

	Average yield (t/ha)	Area (million ha)	Production (million tons)
Soft wheat	1.15	2.18	2.51
Durum wheat	1.03	0.96	1.00
Barley	0.64	1.89	1.22
Total		**5.13**	**4.73**

Official production was then estimated at 5.07 million tons.

TABLE 3.3
Cereals forecasts for the 2012-2013 season in Morocco

	Average yield (t/ha)	Area (million ha)	Production (million tonnes)
Soft wheat	1.93	2.17	4.18
Durum wheat	1.92	0.97	1.87
Barley	1.40	1.98	2.78
Total		**5.12**	**8.83**

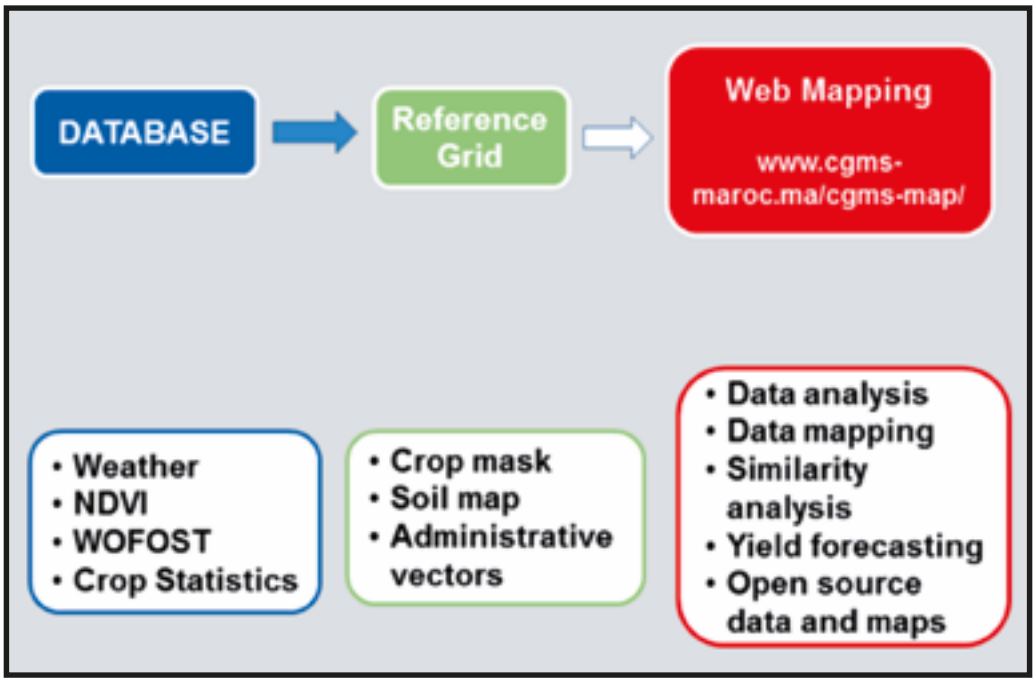
2. Morocco's national official sources: methodology and practices

2.1. Description of the general yield forecasting methodology

2.1.1. The CGMS-MAROC's overall methodology

The CGMS-MAROC is an independent implementation of the MCYFS. A brief description of the MCYFS is given in Annex B3.2. The CGMS-MAROC, developed by INRA in collaboration with the UoL, VITO and the JRC, is designed around a database, a reference grid containing digital layers, and web mapping tools for data analysis and yield forecasting (Figure 3.2 below).

FIGURE 3.2
The design of the CGMS-MAROC's system



Source: Balaghi et al. 2013.

The CGMS-MAROC is designed around three elements: 1) a database containing weather, vegetation and simulation model indicators; 2) a reference grid with cells having a size of 4.5 x 4.5 km2 on agricultural areas, and of 9 x 9 km2 covering the entire territory of Morocco; and 3) a web mapping tool for data mapping and analysis.

The CGMS-MAROC is a crop yield forecasting system that is based on a "combined approach". This means that several statistical and process-based models are combined.

Examples of these methodologies are:

- analysis by analogy, which is performed on the basis of a rainfall or vegetation index (NDVI[23]);
- analysis of a single or a multiple linear regression, performed on the basis of a rainfall or a vegetation index (NDVI); and
- analysis by means of crop growth simulation models, such as the WOFOST[24] model used to forecast cereals yield.

The combined approach is capable of predicting crop yields in different ways, by simultaneously using different independent methodologies. It may be used when no approach – empirical or simulative – exists that, taken separately, can provide a satisfactory prediction accuracy.

2.1.2. Input data

The CGMS-MAROC enables the monitoring of crop development on the basis of the weather, soil characteristics, and crop parameters. The list of input data, the frequency of updating, and the data supplier are shown in Table 3.4 below.

TABLE 3.4
Input data, frequency of updating and supplier

Input data	Frequency of updating	Supplier
Geographic Information System (GIS) maps	Permanent data	INRA
Historical time series meteorological data	Permanent data	DMN
Current meteorological data	Daily	DMN
Historical time series phenological data	Permanent data	INRA
Phenological data	Annual	INRA
Physiological data	Permanent data	INRA
Pedological data	Permanent data	INRA
Historical time series crop yield data	Permanent data	DSS
Historical time series Remote Sensing imagery	Permanent data	VITO
Current Remote Sensing imagery	10-day	VITO

Source: Balaghi et al. 2013.

The system consists of three levels, described below; the list input data are shown in Figure 3.3 below:

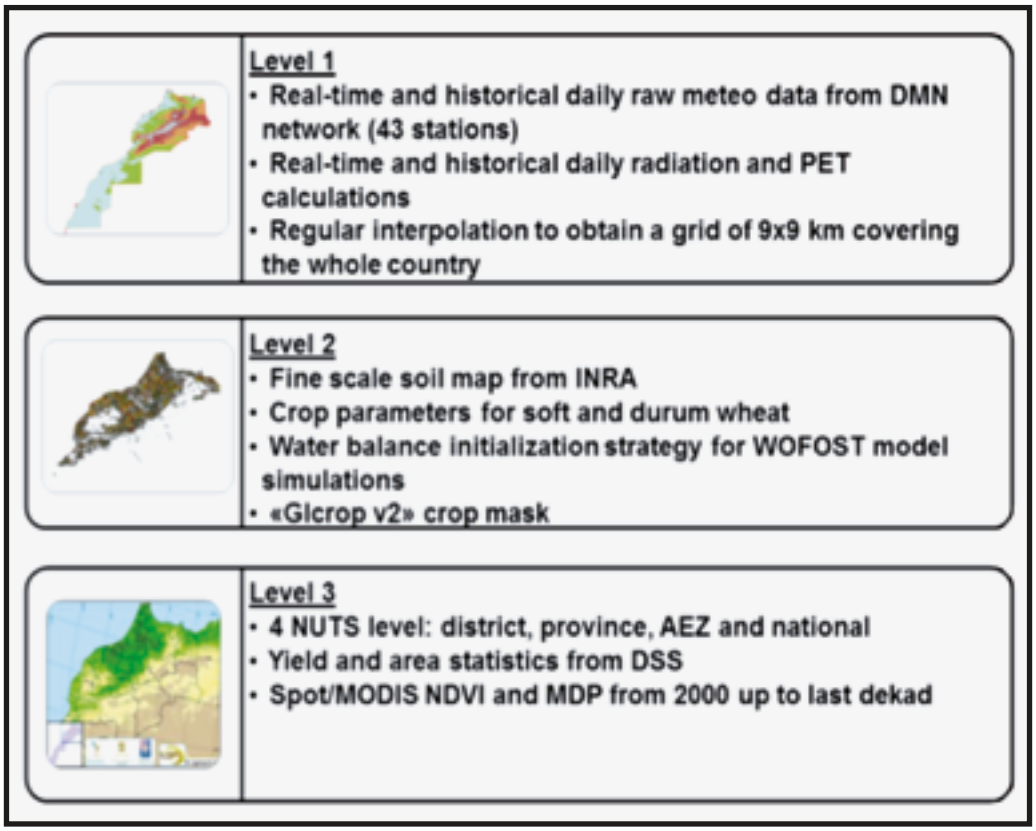
- Level 1: Collection of meteorological data and interpolation over a grid of 9 x 9 km^2 resolution for the entire country;
- Level 2: Simulation of crop growth, applying several agro-meteorological simulation models;

[23] NDVI (Normalized Difference Vegetation Index) is a measurement of plant growth (vigor), vegetation cover, and biomass production from multispectral satellite data. NDVI is calculated from the red and near-infrared (NIR) spectral channels as: NDVI=NIR–red/NIR+red.

[24] WOFOST: http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/alterra/Facilities-Products/Software-and-models/WOFOST.htm.

- Level 3: Forecast of crop yield, using a combined approach involving the parametric and non-parametric statistical analysis of meteorological data, simulation data, and satellite data.

FIGURE 3.3
Input data for Levels 1, 2, and 3 of the CGMS-MAROC



Source: El Hairech et al., FP7-E-Agri meeting 2014[25].

The CGSM-MAROC consists of three levels of implementation; the sets of input variables related to each level are described in this figure.

2.1.3. GIS data

The CGMS-MAROC's spatial digital data are provided by the INRA and consist of several layers, which are combined and loaded into the CGMS-MAROC database and the database for the CGMS-MAROC Statistical Toolbox.

The basis for the spatial schematization of the CGMS-Maroc is a uniform grid, the cells of which have a size of 9 x 9 km^2 and that covers the entire Moroccan territory. A finer interpolation, at 4.5 x 4.5 km^2, is performed for agricultural regions, using the GlCropV2 crop mask.

[25] FP7-E-Agri meeting 2014: http://www.e-agri.info/meetings/meeting_07_presentations.html.

The 1:1,000,000 soil map of Europe is combined with a more detailed soil map that was available only for the agricultural zone in the northern part of Morocco. Moreover, the soil's hydraulic properties were estimated for the spatial units in the Moroccan soil map.

The land cover mask derived from the GlobCover[26] project is also employed. From this map, the classes relating to arable land are derived, to calculate the percentage of arable land per CGSM grid.

The administrative regions for Morocco, consisting of four levels, are taken into consideration; these levels are district, province, agro-zone and entire country.

2.1.4. Meteorological data

In the CGMS-MAROC, the data collected on a daily basis through the network of 40 meteorological stations (see Figure B3.3, Annex B3.1) are used in two ways: as indicators for weather monitoring and as inputs for the WOFOST crop growth model. The weather monitoring component constitutes the core of the CGMS-MAROC at Level 1. This component consists of the following steps:

- Acquisition, quality checking and processing of raw daily meteorological station data from the DMN network;
- Computing and estimating the actual vapour pressure;
- Estimating global radiation according to the hierarchical technique (applying the Ångström[27] and Hargreaves[28] formulas);
- Calculation of advanced parameters: reference evapotranspiration according to the Penman-Monteith[29] formula, evaporation of water surface and evaporation of wet bare soil; and
- Spatial interpolation to the regular Moroccan climatic grid.

Daily historical meteorological data from 1987 to 2012 are part of the climatogical database managed by DMN, and are checked for quality and consistency. Historical time series and current data are all inserted into a single database, which includes the parameters of minimum and maximum temperature, rainfall, cloud cover and sunshine duration, daily mean vapour pressure and daily global radiation at surface (as per Table 3.5 below).

[26] ESA GlobCover portal: http://due.esrin.esa.int/page_globcover.php

[27] The Ångström formula is R_g=R_a*(A_a+B_a*(n/L)), where R_g is the global radiation, R_a is the Angot radiation, n represents the bright sunshine hours per day, L is the astronomical day length, and A_a and B_a are the regression coefficients that depend on the geographical location. The Angot radiation is the amount of extraterrestrial radiation; for its calculation, see Supit et al. (1994).

[28] The Hargreaves formula is R_g=R_a*A_h*√((T_max-T_min))+B_h, where A_h and B_h are the regression coefficients that depend on the geographical location.

[29] The Penman-Monteith equation may be viewed at: http://www.fao.org/docrep/x0490e/x0490e06.htm

TABLE 3.5
Meteorological variables in the CGMS-MAROC

Variable	DESCRIPTION	UNIT
DAY	Date	DATE
MAXIMUM_TEMPERATURE	Daily maximum air temperature	°C
MINIMUM_TEMPERATURE	Daily minimum air temperature	°C
VAPOUR_PRESSURE	Daily mean vapour pressure	HPA
WINDSPEED	Daily mean wind speed at 10 m height	m/s
RAINFALL	Daily rainfall	Mm
SUNSHINE	Daily sunshine duration	H
CLOUD_DAYTIME_TOTAL	Daily mean of total cloud cover	Octas
RAD_MEA	Daily global radiation at surface	KJ/m^2/day
E0	Daily potential evaporation of water surface	mm/day
S0	Daily potential evaporation from a moist bare soil surface	mm/day
ET0	Daily potential transpiration from a crop canopy	mm/day

Significant gaps were found in the historical time series database with regard to the daily mean actual vapour pressure. Because this variable is necessary to calculate the reference evapotranspiration with the Penman-Monteith formula, an estimate value based on the minimum temperature was used instead. Daily data from meteorological stations are collected through the Moroccan Climatological Database, but these do not contain the reference evapotranspiration; this parameter must therefore be calculated according to the Penman-Monteith formula, using the following variables:

- potential evaporation of water surface (mm/day);
- potential evaporation of wet bare soil;
- potential evapotranspiration of a crop canopy.

2.1.5. Crop data

Crop experimental data were provided by the INRA and consisted of crop calendars and yields for several soft wheat and durum wheat cultivars over the 2000-2005 period, for several experimental stations in the country that were located in sub-humid and semi-arid environments. These data were derived from previous crop monitoring projects. The database also contains historical time series, at provincial level, of crop acreage, yield and production as supplied by the DSS. Some calibration influenced the WOFOST TSUM1 and TSUM2 parameters, which define the temperature sums from emergence to flowering and from flowering to maturity. The value of 110-degree days for TSUMEM (sowing to emergence) was taken from existing datasets for spring barley. The calibration began with Karim durum wheat and Achtar soft wheat, because these are the most commonly used varieties in Morocco. The crop calendar is defined with a fixed sowing date on 1 December; the model is then allowed to run until maturity. In estimating the initial soil water, the simulation is commenced on 1 June with a completely dry soil profile. This approach allows for six months during which water can be accumulated in the soil profile before the crop simulation begins on 1 December.

2.1.6. Soil data

Updating the DSS crop mask with the GlcropV2dataset (see Figure B3.4 of Annex B3.1) allowed for a new crop mask to be obtained, at a higher resolution. This is a significant improvement of the model, which enables it to better identify cropped areas. In the future, it is expected that the CGMS-MAROC will be capable of operating in complete independence from the support of foreign institutions such as the EU-JRC.

2.1.7. Remote sensing data

Due to the country's geomorphological characteristics, remote sensing products provide crucial support to agricultural monitoring activities such as crop yield forecasting and acreage estimation. Because Morocco is a semi-arid country, most of the agricultural areas are rainfed, cereals are the predominant crops, and good crop statistics for the main crops are available, remote sensing indicators present good correlation with cereal crop production. Therefore, the Government of Morocco greatly emphasizes the application of this technology in the context of agricultural development. Compared to climate data, remote sensing indicators such as the NDVI have the advantage of covering the whole country, on a continuous basis, and at high spatial and temporal resolutions (see Figure B3.5, of Annex B3.1). Indeed, the network of synoptic meteorological stations (44 in total) covers only part of the national territory; furthermore, most of its stations are located in the Atlantic plains, with only a few situated in mountain and pastoral areas. Crop yield forecasting is possible at agro-ecological zone level from the end of March. The relationship between the autumn cereal yields and the NDVI (SPOT-VEGETATION) is very strong at agro-ecological zone level, with the exception of the Saharan zone. In late April, forecasts can be computed with minimal error for the three species (soft wheat, durum wheat and barley). This relationship is less consistent at agro-ecological zone level than at national level; it is stronger for the Favorable, Intermediate, and Unfavorable South zones than for the Mountain, Unfavorable East and Saharan zones.

The database contains historical time series of NDVIs at a resolution of 1 x 1 km^2, provided by VITO. The web mapping tool incorporated in the CGMS-MAROC enables the visualization and analysis of NDVI imagery at pixel level (see Figure B3.6, of Annex B3.1).

2.1.8. The crop growth model

The CGMS-MAROC is an improved version of the European system CGMS, because it integrates, in addition to the WOFOST model, certain statistical models for forecasting cereal production that were developed by the INRA on the basis of the NDVI. The system was also enhanced by replacing the initial 25 x 25 km^2 climate resolution grid with a finer grid of 10 x 10 km^2 resolution, using the AURELHY[30] interpolation method as adapted by the DMN. The crop monitoring component produces simulated crop indicators, such as biomass and yields, to show the effect of recent weather on crop growth. The work is divided into four activities, set out below; of these, only the last two are part of the operational services, while the first

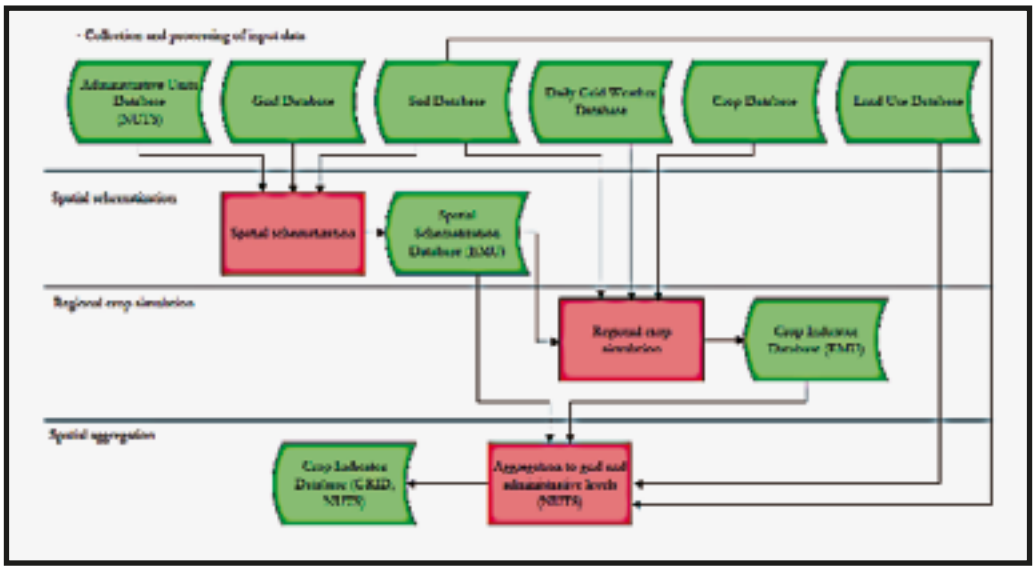
[30] AURELHY: Analyse Utilisant le RElief pour les besoins de l'HYdrométéorolgie, http://www.e-agri.info/meetings/meeting_02/Presentation/Rabat_AURELHY_TARIK_ELHAIRECH.pdf

two are pre-processing tasks (see Figure 3.4 below):

- Collection and processing of input data;
- Spatial schematization;
- Running of crop simulations for individual map units;
- Spatial aggregation of results.

The crop monitoring component in the CGMS-MAROC is based on the WOFOST crop growth simulation model, which is a point process-based model. To apply this model on a greater scale, it is necessary to identify areas in which the meteorological data, soil characteristics and crop parameters can be assumed to be homogeneous. It is also assumed that the simulated crop growth is representative for those areas. To construct these areas, two geographical layers (the climatic grid cell and the SMU) are intersected; this results in the EMU. Furthermore, a crop mask digital file is used to exclude the non-arable areas and to retain only the intersection between the climate grids, the SMUs and the arable lands. The EMUs are, therefore, WOFOST's smallest units of simulation (see Figure B3.7, of Annex B3.1).

FIGURE 3.4
Overview of the CGMS-MAROC crop monitoring components



Source: Balaghi et al. 2013.

The crop monitoring component of CGMS-MAROC is implemented in four phases: 1) Collection and processing of input data; 2) Spatial schematization; 3) Running of WOFOST crop simulations for individual map units; and 4) Spatial aggregation of results.

The EMUs' simulated crop indicators are spatially aggregated to the smallest administrative polygons. The aggregation from EMUs to administrative regions at Level 3 is based on each EMU's weight within the region of interest. This weight is the area fraction of the EMU that is covered by the selected crop in relation to the total area of all EMUs within the district. The results of the crop monitoring component contain the columns set out in Table 3.6 below.

TABLE 3.6
Level 2 outputs in CGMS-MAROC

Variable	Unit	Description
CROP_NO	#	crop number
GRID_NO	#	grid number
SMU_NO	#	soil mapping unit number
DAY	DATE	Date
POTENTIAL_YIELD_BIOMASS	kg/ha	potential dry weight biomass
POTENTIAL_YIELD_STORAGE	kg/ha	potential dry weight storage organs
WATER_LIM_YIELD_BIOMASS	kg/ha	water limited dry weight biomass
WATER_LIM_YIELD_STORAGE	kg/ha	water limited dry weight storage organs
POTENTIAL_LEAF_AREA_INDEX	m2.m2	potential leaf area index: leaf area divided by surface area
WATER_LIM_LEAF_AREA_INDEX	m2.m2	water limited leaf area index: leaf area divided by surface area
DEVELOPMENT_STAGE	#	development stage of crop 0-200
RELATIVE_SOIL_MOISTURE	%	percentage of (field capacity minus the wilting point)
TOTAL_WATER_CONSUMPTION	cm	sum of water limited transpiration
TOTAL_WATER_REQUIREMENT	cm	sum of potential transpiration
FSM	#	volumetric soil moisture content in rooted zone
FSMUR	#	volumetric soil moisture content in not rooted zone
LEAVES_DIED_BY_COLD	#	fraction of leaves died by cold weather, total biomass
RUNOFF	cm	run off
SOIL_EVAPORATION	cm	soil evaporation
LOSS_TO_SUBSOIL	cm	amount of water drained to the sub soil and therefore lost for the crop

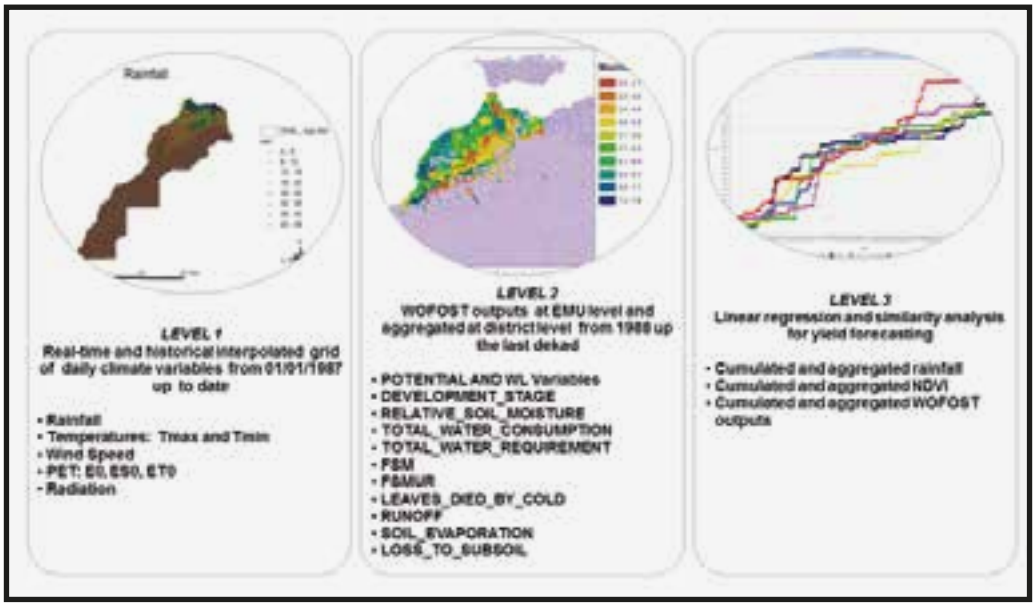
Source: Balaghi et al. 2013.

In the CGMS-MAROC, Level 3 is chosen, which represents the geographical layer of districts (communes); one of the results is shown in Figure B3.8, Annex B3.1.

2.1.9. The output data

The CGMS-MAROC enables crop development to be monitored on the basis of the weather, the soil characteristics and the crop parameters. The system consists of three levels; a list of output data is illustrated in Figure 3.5 below.

FIGURE 3.5
Output data from Levels 1, 2 and 3 of the CGMS-MAROC



Source: 2014 E-AGRI meeting[31].

Each level of the CGMS-MAROC produces a set of output data, i.e. a real-time and historical interpolated grid of daily climate variables for Level 1; the WOFOST output at EMU and district levels for Level 2; and linear regressions and similarity analyses for yield forecasting at Level 3.

2.1.10. The crop yield forecast

The CGMS-MAROC adopts a combined approach for crop yield. Further details are available in Section 2.1.1 above.

Analysis by analogy (or similarity) is an effective, fast and simple method to forecast cereal yields. It consists in the identification of the previous cropping seasons that were agro-climatically similar to the season under study. This statistical analysis assumes that a cropping season having similar agro-climatic conditions to past ones would result in similar crop yields, assuming that all other factors have remained equal. Of course, this approach can only be used if a cropping season with similar climatic conditions can be found in the past seasons. Therefore, a long time series of meteorological data is needed, so that a wide range of large agro-climatic variation may be taken into account. Specific cropping seasons presenting peculiar conditions, such as extreme moisture or extreme cold, have little chance of being encountered within historical seasons, and will thus be forecasted with a higher margin of error. While this approach makes reference to real past agro-climatic situations, crop yield forecasted on the basis of a similarity analysis must be adjusted to take into account the technological trends (e.g. cultivar, sowing, fertilization, machinery, irrigation, crop protection, inputs, etc.) that have developed in the time between the similar cropping seasons. For this

[31] E-AGRI: http://www.e-agri.info/meetings/index.html

type of analysis, it is also possible to envisage a forecasting error, considering that the similar seasons, if any, are a sample of all similar seasons. Similarity analyses can be performed through the following: visual graphics, simple statistical techniques, principal components and cluster analyses. One or more agro-climatic factors, such as rainfall, temperature or vegetation indicators (e.g. the NDVI or the DMP) can be used for the analysis. Similarity analyses are used to forecast cereal yields as early as the month of February, using rainfall or the NDVI. Because the climatic conditions of the months of March and April are decisive for final cereal yields, signs of bad or good cereal harvests may be observed as early as the end of February.

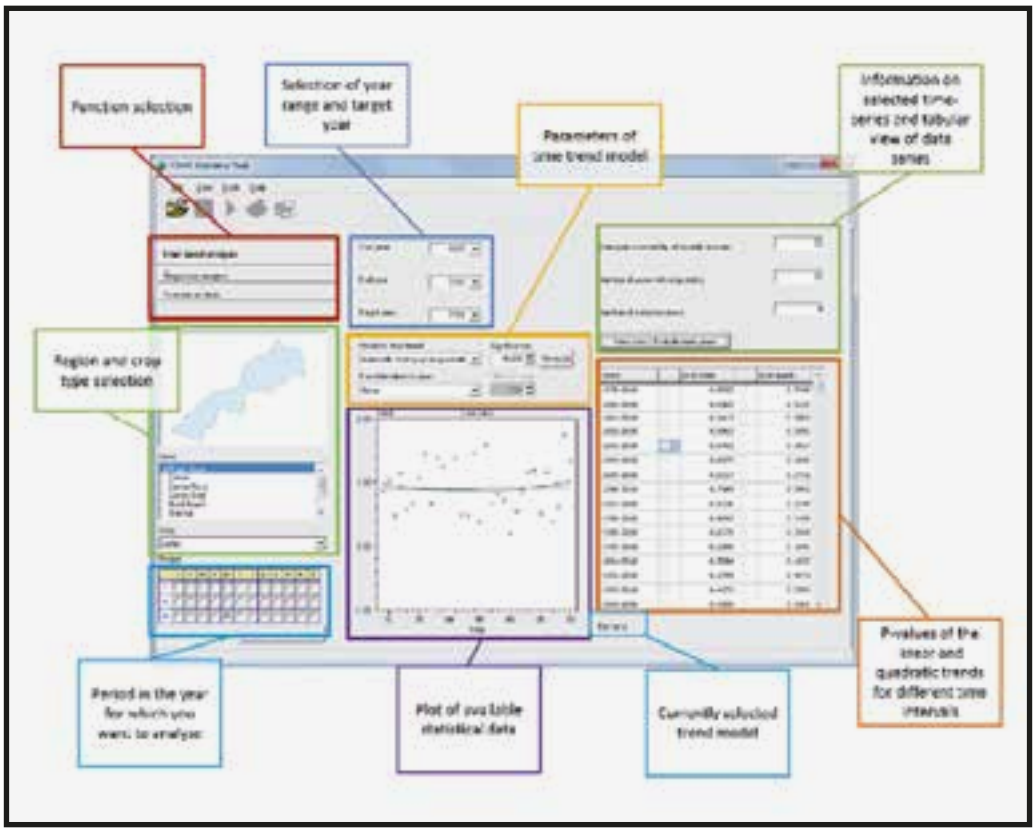
The linear regression analysis uses the ordinary least-squares method to identify the relationships between crop yields and agronomic, environmental or economic variables, which are used as predictors. Predictors can be either agronomic factors (variety, temperature, fertilizers, irrigation, etc.), climatic factors (rainfall, temperature, humidity, etc.), environmental indicators (NDVI, water balance, etc.), or economic indicators (price, cost, accessibility, etc.). Indicators are used in crop forecasting because they can complete the agronomic and climatic factors that are directly used. For example, the NDVI is a measure of the vegetation's vigour and is the result of measurements of rainfall, temperature, soil water balance, the agronomic techniques used, etc. However, it is difficult to quantify the contribution of each factor to the NDVI. The predictors can be either quantitative variables (rainfall, temperature, NDVI, etc.) or qualitative variables (presence or absence of drought, etc.), used separately or in combination. In Morocco, the predictors to be considered for cereal yield forecasting are: the rainfall, the temperature and the vegetation index (NDVI and derived indices). They can be computed for the entire cropping cycle or for parts thereof, and can be used in a simple linear regression model with yield, or in combination, in multiple regression equations.

The results of the aggregated crop simulation at regional level are the indicators that are used for crop yield forecasting by means of the CST. The results from the CGMS-MAROC at Level 2 are sent to the CST database and, at the same time, further indicators are added, which are derived directly from the weather data and from satellite processing chains at VITO. The CST incorporates a tool to perform linear regression and similarity analyses for cereal yield forecasting (see Figure 3.6 below). The estimate of the forecast error is a fundamental quality of a crop forecasting system. For example, the JRC considers that the forecast error is low when it is lower than 3 percent and no higher than 6 percent (Genovese & Bettio 2004). The European CGMS' forecasting system provides figures for the yields of major crops in Europe with an error between 3 and 5 percent (8.6 percent for wheat). The accuracy of the CGMS-MAROC's cereal yield forecasting (see Figure 3.7 below) is continuously refined, because it depends upon four essential parameters that are subject to constant improvement:

- The number of years during which data is recorded, which helps to build better databases that account for more diverse situations; this, in turn, can train the regression models;
- The number of meteorological stations within the DMN's network, but also within the Ministry of Agriculture and Marine Fisheries and the INRA; this will enable better assessment of climatic conditions;

- The agricultural mask, that will enable the agricultural areas to be separated from other types of land (forest, grazing, uncultivated, lakes, cities, etc.);
- The NDVI, in terms of the quality of satellite images, the spatial resolution and the cost.

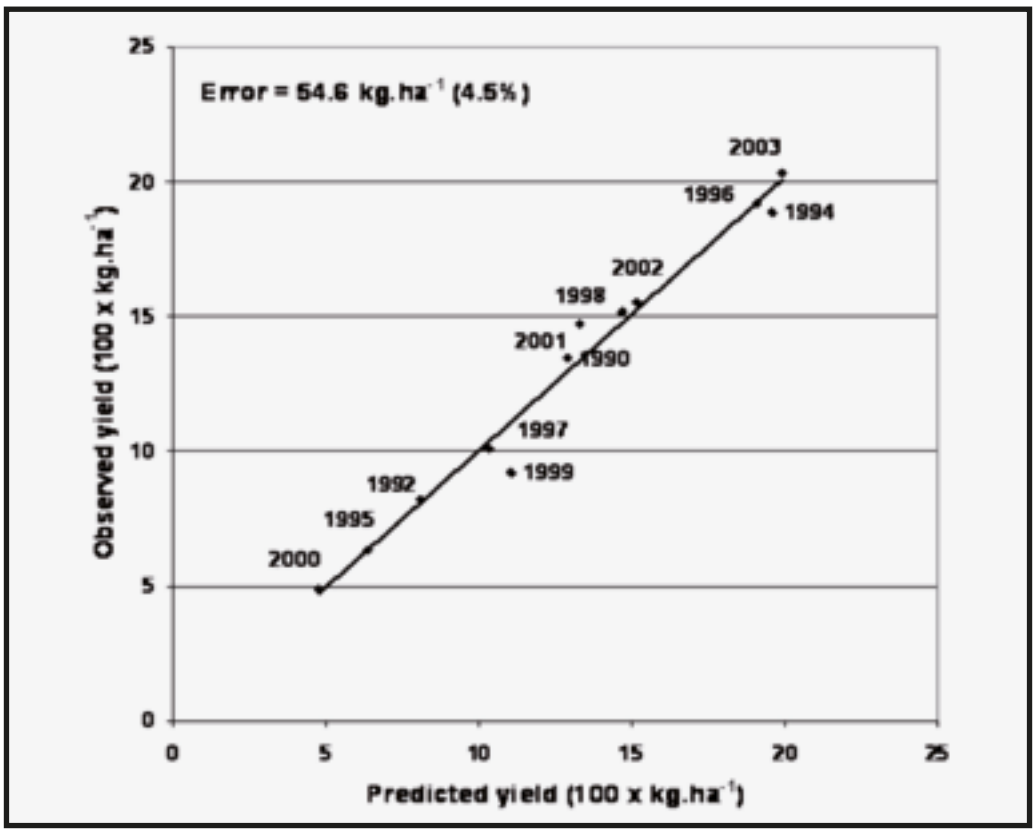
FIGURE 3.6
The linear regression and similarity analysis tool



Source: El Hairech & Balaghi 2014.

The CST incorporates a tool to perform linear regression and similarity analyses for cereal yield forecasting. This tool enables selection of the regression function to be used, the type of trend model, the region and the crop type of interest, and other parameters.

FIGURE 3.7
Linear regression between observed and predicted yields

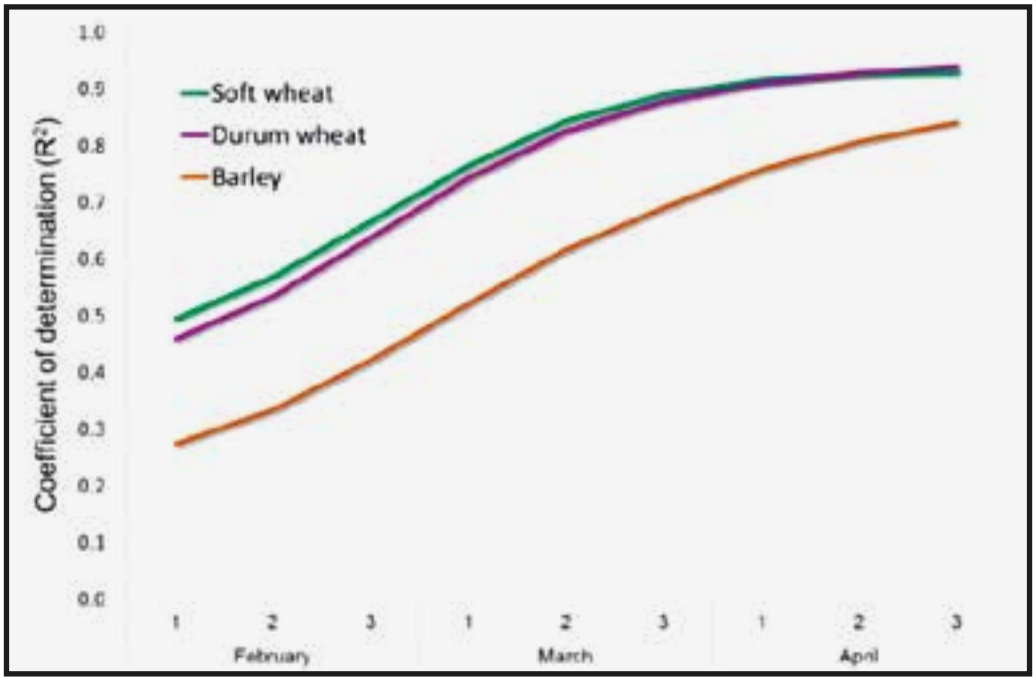


Source: El Hairech & Balaghi 2014.

The accuracy of the CGMS-MAROC's forecasts is constantly refined, as they depend on four parameters that are subject to continuous improvement: the historical data available, the number of meteorological stations covering the country, the availability of an agricultural mask, and the quality of the NDVI.

The consistency of crop yield forecasting at national level improves as the growing season progresses (see Figure 3.8 below); the use of different indicators increases its precision (Table 3.7 below).

FIGURE 3.8
The coefficient of determination (R2) of regression models between yields of the three main cereals (soft wheat, durum wheat, and barley) at national level from February to April (data from 1999 to 2011)



Source: 2014 E-AGRI meeting[32].

The accuracy of crop yield forecasts at national level increases as the growing season progresses.

TABLE 3.7
Cereal production in Morocco (millions of tons)

Cropping season	EU-CGMS	NDVI	Rainfall	Official
2008 - 2009	10.6	8.5	9.6	10.2
2009 - 2010	7.8	7.2	9.3	7.5
2010 - 2011	8.7	9.0	9.6	8.4

Source: 2011 E-AGRI meeting.

2.2. Relevant practices for data collection

In the system, two types of data are used: permanent data over time and data evolving over time. Prior to the operational phase, an initial phase is performed for collecting permanent data over time: phenological data, physiological data, soil data, GIS digital maps (administrative boundaries, soil map, DEMs, etc.), meteorological data (historical time series), and historical

[32] E-AGRI: http://www.e-agri.info/meetings/index.html

crop statistics. Human and data processing time is an important issue to consider when evaluating the cost of the overall data collection process; this cost may be borne either by the data provider or by the data recipient, and may also be provided in kind, as in the case of team partners. Although data are now processed in digital format, the provider and the recipient often use very different formats. Thus, a great proportion of time is spent on data re-formatting, as the data must be adapted to the input requirements linked to specific applications (e.g. WOFOST), and databases must follow these requirements.

Future developments will seek to improve the following:

- The CGMS, based on NDVI and Rainfall values adapted to the semi-arid environment of Morocco, and by combining mechanistic modelling and statistical modelling;
- Scenarios, through seasonal weather forecasts (North Atlantic Oscillation);
- Forecasts, including the diseases lost;
- Climatic data, on the basis of the DMN's interpolation method.

In addition, a more independent extension of the collaborative agreement between the INRA and the JRC will be sought, and to include therein also the DMN and DSS.

2.3. Relevant practices for data sharing and analysis, harmonization, and integration

The public may freely access the CGMS-MAROC web mapping application[33] (see Figure B3.6, Annex B3.1), to monitor meteorological conditions (rainfall, average temperature, maximum temperature, minimum temperature, radiation, evapotranspiration), and the current and historical NDVIs of growing season, with the tools and information developed at Level 1 of the CGMS-MAROC. The system enables different types of agro-meteorological analysis for different timespans (days, 10-day, month) and spatial scales (country, province, commune and climate grid). The system also allows for the comparison of the current season's weather conditions to those of the historical database. Recently, an Android app has been developed to enable access to the CGMS-MAROC by cellular phone. This app provides information relevant to monitoring the crop year at any location in Morocco, which may be identified by GPS localization or by typing in the location.

Plans to expand the capabilities offered by the CGMS-MAROC Level 2 in the near future are currently under way (Balaghi et al. 2013).

2.4. Human, financial, and technical infrastructure

The Ministry of Agriculture is responsible for agricultural statistics, and is also one the CGMS-MAROC's main partners. The CGMS-MAROC is coordinated by national institutions

[33] Web mapping: http://www.cgms-maroc.ma/cgms-map/

involved in agriculture, and is supported through national and international projects (e.g. E-AGRI and JECAM[34]). The system also enjoys strong support from VITO[35], which is an essential partner of the system because it provides a regular supply of remotely sensed imagery and updating of the system as more advanced data becomes available with the use of new types of sensors. The knowledge developed within the CGMS-MAROC can be transferred to other developing countries, potentially within the framework of a specific project (e.g. the Global Monitoring for Food Security – GMFS – project[36] funded by the European Space Agency, ESA).

2.5. Institutional structure and sustainability

Currently, the CGMS-MAROC system is used to forecast cereal yield at national, agro-ecological zone and provincial levels. This system is coordinated by the INRA and is managed with the DMN and the DSS through a tripartite agreement. The system is intended to support the DSS in its mission of crop yield forecasting, and is installed on a central server at the DMN; the latter is responsible for delivering the climate grid, updating statistical data and providing IT support. The CGMS-MAROC is the first operational system for agrometeorological crop forecasting in Morocco; its institutionalization in the strategic tripartite partnership enables its development and sustainability. The roles of the national institutions in charge of the CGMS-MAROC is detailed below:

- INRA
  - Coordinating the system;
  - Collecting and providing agronomic data to calibrate the system (Level 2);
  - Contributing, with the DMN and the DSS, to the statistical analysis for determining the yield forecasting scenarios (Level 3);
  - Analysis of data from satellite imagery to predict crop yields (Level 3).
- DSS
  - Collecting and providing the data on areas and crop yields necessary for the CGMS-MAROC's proper functioning;
  - Computing the estimates of agricultural land by processing satellite images and field surveys.
- DMN
  - Hosting and IT maintenance of the CGMS-MAROC server for the benefit of all three institutions;
  - Interpolating the climate data that is part of the weather stations' network and the use of the CGMS-MAROC's interpolated data (Level 1).

[34] JECAM Belgium/France: http://www.jecam.org/?/project-reports/belgium-france
[35] VITO: http://www.vito-eodata.be/PDF/portal/Application.html#Home
[36] GMFS: http://www.gmfs.info/

2.6. Innovation and integration with regional- and global-level initiatives

The specific prediction system of CGMS-MAROC, which adapts the European CGMS to the circumstances of Morocco, was developed as part of the E-AGRI project[37].

3. Linking up with crop production forecasts: the practices followed by Morocco's official national sources

3.1. Which area data is used? The methodology applied

Four official national sources release data on cereal crop production: estimates are generated by the DSS and by the HCP[38]. Production forecasts are elaborated by the CRTS[39] and by BAM[40].

The documents produced by the HCP, the CRTS and the BAM are not available to the public, because the crop production estimates produced by these entities are for internal use only.

3.1.1. The Direction of Strategy and Statistics

The Ministry of Agriculture's DSS is in charge of agricultural surveys since 1975. At the central level, the DSS is responsible for designing and conducting surveys, coaching regional teams, and analysing and publishing results; at regional level, the statistical services are responsible for filling out questionnaires on the samples within their areas, and verifying and inputting the data collected. Data entry is performed by the agricultural statistics' regional services. The DSS does not have enough professionals to undertake the work programme of the entire division. Over the past fifteen years, the number of agents assigned to work on field surveys has declined by more than 75 percent. This persisting decrease of staff poses a serious threat to the performance of the necessary statistical operations (Serghini 2012). Sampling errors are mastered, but are neither published nor calculated. The samples were drawn in the 1980s, and are currently being renewed. Data collection errors are neither evaluated nor documented and, due to the lack of staff, ground checks are irregular and unsystematic. However, this weakness in control mechanisms is balanced by the extensive experience of all enumerators. Significant efforts are being made to reduce errors in data collection, notably by adopting the area sample that enables closed segments to compare farmers' declarations on the land to the area measured in aerial photographs. However, for errors relating to other variables, the efforts are limited and undocumented.

[37] E-AGRI: http://www.e-agri.info/index.html
[38] HCP: http://www.hcp.ma/
[39] CRTS: http://www.crts.gov.ma/Royal%20Centre%20for%20Remote%20Sensing
[40] BAM: http://www.bkam.ma/

3.1.1.1. Area and Methodology used by the DSS

Crop statistics are collected on the basis of Area Frame Sampling (AFS) for the croplands. The crop type acreage is improved by combining the estimates obtained in the field survey with the estimates produced by means of image classification. Combining the two sets of data may reduce field sampling error, on one hand, and image classification errors, on the other.

Data on yield and acreage for each of the three autumn cereals[41], soft wheat, durum wheat and barley are available for 40 provinces of the country, for the seasons from 1978-1979 to 2010-2011 (Mahyou et al. 2013). These datasets are compiled from sub-province sample surveys and are released in official documents, as provincial averages. As mentioned above, crop statistics are collected on the basis of AFS for the croplands. Between 10 February and 30 March of each year, acreage estimates of cereals are computed by the DSS from the AFS of 3,000 secondary sampling units (19 million hectares), which may also be referred to as segments. The AFS is essentially a complete listing of the entire population of units to be sampled. In the AFS methodology, the units to be sampled are areas of land. The methodology consists of three main steps: stratification, zoning and sampling. Stratification is performed according to irrigated cropland, non-irrigated cropland, orchards, forests, towns, and villages; the sampling is replicated (two-stage sample design, segments' physical boundaries) (Craig et al. 2013).

The DSS has updated this sample since 2008, by incorporating modern geomatic techniques (remote sensing and GIS); these enable the estimating factors' precision to be improved. For this purpose, the DSS has developed a specific GIS application, which automates all stages of the sampling development. For each segment, the yield is estimated using the classical method of directly harvesting the representative plots and re-sampling within the segments. The cereal production of each segment is thus the product of the acreage and the yield. The production and acreage data are then aggregated by province. During the cropping season, the DSS carries out crop monitoring, and acreage and cereal yield estimation in three phases:

- Phase 1: "Survey on crop monitoring", in February to assess the crop growth stage and sowing status;
- Phase 2: "Survey on land use", between February to June, to estimate crop acreage;
- Phase 3: "Survey on provisional production", in April (1 to 2 months before harvest), to estimate the production of three major cereals: soft wheat, durum wheat and barley.

In 1983, in cooperation with the United States Department of Agriculture's National Agricultural Statistics Service (USDA/NASS), Morocco's Ministry of Agriculture built a fully operational survey program based on area sampling frames, which enabled probability-based samples to be drawn for the ultimate purpose of estimating crop areas using aerial photos. However, these samples have become obsolete, and sample renewing by means of the old procedures appears to be cost-ineffective, as well as consuming in terms of time and

[41] These cereals are called autumn cereals because they are sown during this season, unlike the spring cereals such as maize or sorghum.

efforts. Furthermore, administrative borders have been changed several times, which makes it difficult for the statistics to relate to regions with new borders. Aerial photography has been used since 1980. Today, remote sensing digital images from the Spot-5 satellite are used as the primary input for land cover stratification (DSS 2011). This satellite imagery provides a much better frame for strata boundaries than do aerial photos, proving to be not only cost-effective but also capable of enabling more accurate crop area estimates. Furthermore, such imagery allows Morocco to move from area sampling frames based on paper products – which risk being destroyed by fire or lost – to digital versions, which are more accurate and may be better protected from loss. Indeed, a new project, entitled the "Al Majal Operation" (FAO 2009), and based on updated high-resolutions images acquired from the CRTS[42], helps to address most of these issues, enabling the construction of a basic and dynamic tool for collecting agricultural statistics.

3.1.2. The High Commission for Planning of the Directorate of Statistics

The HCP is a ministerial body created in 2003. It is led by the High Commissioner for Planning, a figure enjoying ministerial rank that is appointed by the King of Morocco. The HCP is the main producer of economic, demographic and social statistical information, and is in charge of preparing the national accounts. The HCP complies with international statistical standards since 2005, and is a member of the UN's Statistical Commission. The main tasks of the Directorate of Statistics are: the conduction of surveys, censuses and studies in the demographic, economic and social fields; the collection, centralization, processing, analysis and organization of statistical data banks using different sources, and their diffusion; ensuring the development and promotion of the national statistical system; the control of the standardization of concepts, the harmonization and the proper use of statistical methodologies within the national statistical system; and the coordination of the statistical work of the system's various components.

3.1.2.1. Area and Methodology used by the HCP-Directorate of Statistics

The HCP-Directorate of Statistics uses three approaches (Bensaid 2011):

- **Yield approach**: the cropped areas are subdivided into 3 classes (good, average, poor) depending on the status of plantings; the cropping status in the provinces is assessed on the basis of rainfall, temperature and the rate at which dams are filled; a retrospective analysis is elaborated, on the basis of the relationship between the "state of sowing" and the "crop performance".
- **Cropping season similarity**: a factor analysis is run with the following variables: total rainfall of fourth quarter, total rainfall of first quarter, cropped area, impact of early rains, legumes/vegetables production, total number of livestock, the psychological effect of the previous cropping season.
- **Econometric modeling**: a linear regression is performed with the autocorrelation of residuals, using the annual change in total cereal production as a dependent

[42] CRTS: http://www.crts.gov.ma/

variable and the total rainfall of the first and fourth quarters, and the impact of early rains as independent variables.

3.1.3. The Royal Centre for Remote Sensing

The CRTS is the national institution in charge of the promotion, use and development of remote sensing applications in Morocco. The CRTS coordinates and carries out the national remote sensing program, in collaboration with the relevant ministerial departments, private operators and universities. The CRTS uses operational systems to collect, produce and analyse data from Earth observation satellites and other sources.

3.1.4. Area and Methodology used by the CRTS

The estimates of the area and of the production of winter cereals (durum wheat, soft wheat and barley) are based on a statistical approach that combines satellite images of representative samples of cereals in Morocco and low-resolution images. At national level, the areas are established by extrapolating the results from 110 satellite image segments. The production is forecast from an average yield (field survey), which is weighted by the information obtained from an image that synthesizes several low-resolution images acquired (from a SPOT[43] satellite) during the month of April (see Figure B3.11, Annex B3.10).

3.1.5. The Bank Al Maghrib

The Central Bank of the Kingdom of Morocco (BAM) is a public legal entity endowed with financial autonomy. It was created in 1959 to replace the former Banque d'Etat du Maroc. BAM also elaborates crop production forecasts on the basis of simple rainfall indicators, within the framework of its activities of monitoring the national economy and the evolution of inflation and growth.

3.1.5.1. Area and Methodology used by the Bank al Maghrib

Three methods are used to forecast yield, all of which are based on an analysis of rainfall at station level, related to the crop yield for the sub-region represented by the station (Bensaid 2011). The first method uses the multiple linear regression between yields as a dependent variable and rainfall (total rainfall, number of rainy days, maximum amount of rainfall in 24 hours) and temperature (mean temperature, average of maximum and minimum temperatures, absolute maximum and minimum temperatures) as independent variables. The rainfall data are provided by the DMN for 29 stations across the country, representing 45 sub-regions. The second method seeks to compare similar cropping seasons, and to determine, for each sub-region, the last cropping season that presented similar climatic conditions (rainfall) to those existing during the current season. This method uses a Principal Component Analysis to assess critical periods with exceptional conditions. This analysis is performed by processing data from 20 weather stations located in the 45 sub-regions; the

[43] SPOT: http://spot5.cnes.fr/gb/index3.htm

results are assigned to each sub-region to estimate the yield. However, this method does not aim for an exact crop production forecast; rather, it is used as an expert assessment of potential yield. The third method uses the amount of rainfall to generate a rainfall index. The assumption is that each weather station has a weight proportional to the final crop production. The equation for calculating this index is:

$$\mathbf{IPLUV = IP_1 \times W_1 + (IP_2 - IP_1) \times W_2 + (IP_3 - IP_2) \times W_3,}$$

where

IPLUV	= the rainfall index;
Wj	= the weight of each reference period considered in relation to its contribution to agricultural production;
Reference period	= 1 {September, October, November, December}; 2 {January, February, March}; 3 {April, May};
W1	= 0,35;
W2	= 0.60; and
W3	= 0.05.

The weights are estimated by means of a non-parametric method, maximizing the function of correlation between the rainfall index and cereal production. The maximum correlation value is approximately 0.93. Finally, the cereal production PCER is a function of the IPLUV:

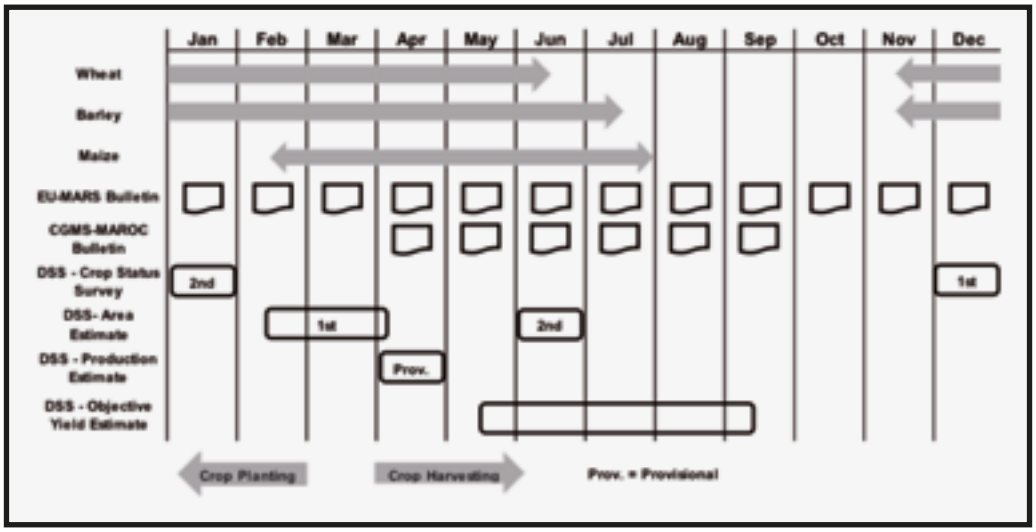
$$\mathbf{PCER = f0\ (IPLUV).}$$

3.2. Release calendars: punctuality and timeliness

The timeliness of the agricultural statistics[44] provided by the DSS is generally satisfactory, although very general information is provided, such as the total cereal area and the production at national level, and the statistics are released between July and September. The agricultural statistics produced are published, but are not freely available. There is no predetermined schedule for the publication of agricultural statistics. The quality of agricultural statistics is neither reported nor documented, and little data analysis is performed. There is no procedure for providing micro-data, and there is no single database that keeps track of the evolution of all agricultural statistics or that stores primary data at farmer levels (Serghini 2012). Other national sources, such as the HCP and the BAM, do not provide such information. Table 3.8 below illustrates the release frequency of yield forecasts and estimates, and acreage and production estimates in Morocco, as well as the planting and harvesting calendars of the main crops.

[44] Agricultural season reports are available at: http://www.agriculture.gov.ma/rapports-statistiques

TABLE 3.8
Crop calendars and release frequency of crop forecasts and estimates



3.3. Human, financial, and technical infrastructure

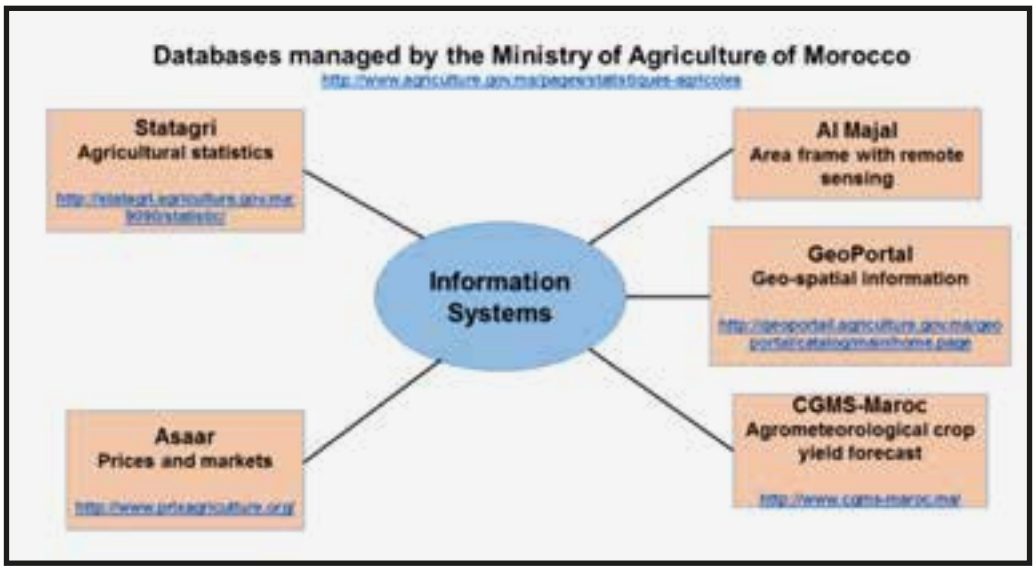
Crop forecasting is a vital element of Morocco's agricultural economy. The various national institutions that are active in this field have keenly demonstrated an interest in the production of advance information. The Government is investing in the application of new technologies such as remote sensing and GIS; this approach is all the more evident from an examination of the many information systems and projects that are coordinated by the Ministry of Agriculture, one of which is CGMS-MAROC (see Figure 3.9 below). The technical level of the CGMS-MAROC's various partners is excellent: for example, the DMN is considered to be one of the two most efficient National Meteorological Services (NMSs) in Africa[45]. The other two main partners, the INRA and the DSS, are both under the Ministry of Agriculture and their infrastructure is well-established. All three institutions have very sound institutional, human and technological infrastructures.

[45] The other one being the South African Weather Service: http://www.weathersa.co.za/

3.4. Institutional structure and sustainability

Because the CGMS-MAROC is coordinated by the Ministry of Agriculture (of which the INRA and the DSS are part), and by the DMN by means of a formal agreement, its establishment is ensured and sustainable.

FIGURE 3.9
Information systems coordinated by the Ministry of Agriculture



Source: Workshop on Crop yield forecasting based on remote sensing, 2011. Rabat, Morocco .

The CGMS-MAROC is one of the many information system projects coordinated by the Ministry of Agriculture, which is investing in the use of new technologies for data production and dissemination.

4

Crop Yield Forecasting in South Africa

Wiltrud Durand[1]

1. Crop yield forecast data for South Africa

1.1. Brief description

The South African agricultural sector has a dual nature: on one hand, it comprises a vibrant, well-integrated and highly capitalized commercial sector; on the other, it features a fluctuating non-commercial and resource-constrained small-scale farming sector (Vink and Kirsten 2003; May and Carter 2009). According to the 2007 commercial agricultural census (Stats SA 2009) there are 39,982 commercial farm units in the country, which produce approximately 95 percent of the agricultural output. The majority of these units are situated on 87 percent of the total agricultural land. In contrast, non-commercial and small-scale farmers produce five percent of the output, on the remaining 13 percent of the agricultural land. The actual numbers of these farmers and their reasons for farming are far from clear. However, according to the 2011 national census, 2.8 million households have reported some form of engagement in agricultural activity: this amounts to approximately 20 percent of the national population.

[1] Agricultural research Council-Grain Crops Institute, South Africa

In administrative terms, South Africa is divided into nine provinces (Western Cape, Eastern Cape, Kwazulu-Natal, Free State, Gauteng, Northern Cape, North West Province, Limpopo and Mpumalanga) which have vastly topographies and climates. Thus, crops in South Africa are produced under extremely variable climate conditions, which results in major yield fluctuations. For example, between the years 2000 and 2013, average South African maize yields fluctuated between three and five t/ha; maize imports between zero and 1.25 million tons; and exports between zero and 0,8 million tons (Spear (Pty) Ltd and BFAP 2014).

Of all the crops produced, maize is the most important commercial grain crop (see Figures B4.1 and B4.2, Annex B4.1) – indeed, maize is both the staple food of the majority of the South African population and the major feed grain source for livestock. Approximately 48 percent of the maize produced in South Africa is white and the remaining 52 percent is yellow (DAFF 2013). White maize is used primarily for human consumption, while yellow maize is mostly for animal feed. Maize, at 60.8 percent, is also the largest contributor towards the gross value of field crops as reported by the Crop Estimates Committee (CEC), while wheat contributes 11.5 percent and soybeans 5.1 percent (DAFF 2013; see Figure B4.2, Annex B4.1).

Prior to May 1997, a Government-instituted Maize Board controlled the marketing of maize and determined the price of maize. This single-channel fixed-price marketing system for maize on the local market was repealed at the end of April 1995, after which the marketing of maize was deregulated. With regard to international marketing, single-channel export pools were operated by the Maize Board until April 1997. Since the deregulation of the South African agricultural market in 1995, the maize market has essentially been open, with a number of basic factors such as international maize prices, exchange rates, local and regional production and national and international stock levels playing a role in determining the local price.

Since May 1997, no statutory levies have been applicable and the marketing of maize is free from statutory intervention. Prices are negotiated according to market forces either by spot, contract or futures prices. There is no government subsidy or any other form of direct financial aid to South African commercial farmers. The only statutory requirement for importers, grain storers (including on-farm storing), exporters and processors is to register and report stocks to the South African Grain Information System (SAGIS) in accordance with the Marketing of Agricultural Products Act (Act no. 47 of 1996).

Thus, to gain a competitive advantage, all parties involved in the South African maize value chain need prior information on the main price-determining factors, such as the size of the local production areas (area planted versus area harvested); the expected yield and how this might be affected by future weather; the size of the crop likely to reach the market; and the current stock levels.

South Africa's official crop forecast for summer crops (maize, sorghum, sunflower seed, soybeans, groundnuts and dry beans) and winter crops (wheat, malting barley and canola) is released monthly by the CEC, while the SAGIS releases monthly information on stock levels. Some producer organizations, agri-business and traders calculate their own crop estimates and forecasts, but these are not made available to the general public. However, these same parties often release comments on the current cropping conditions. The forecasts produced

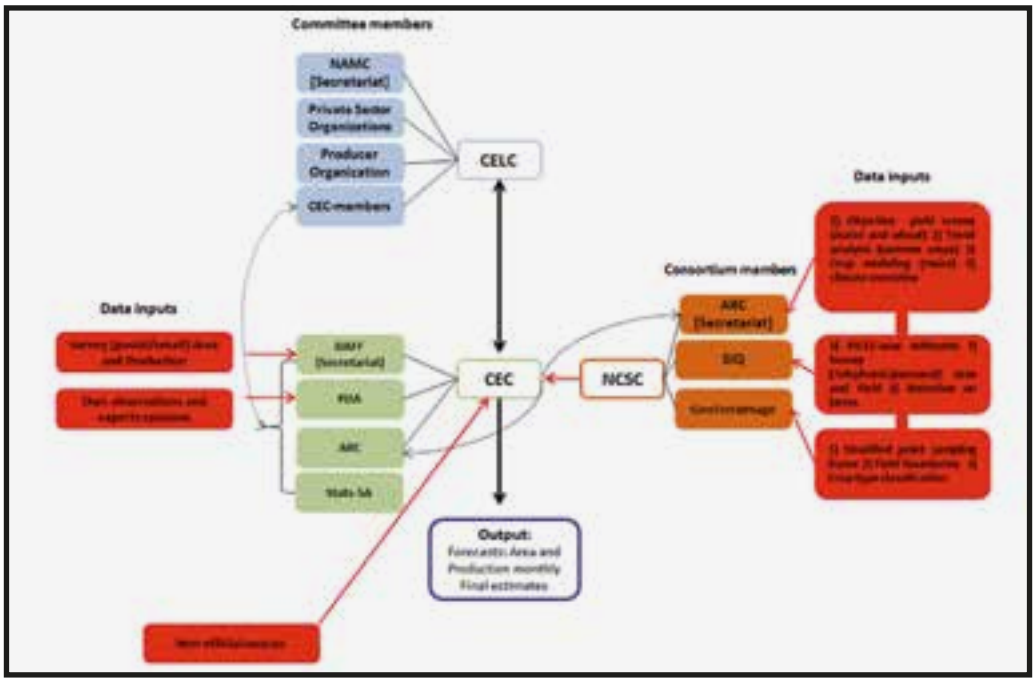
by the CEC are based on data from different input providers. Yield forecasts are based on two surveys (conducted by post/e-mail and telephone); an objective yield survey (OYS) is performed for maize and wheat crops, a trend analysis is conducted for the summer crops and a crop modeling is performed only for maize. Area estimates are computed relying upon a statistics-based aerial survey and two surveys (conducted by post/e-mail and telephone). The actual estimate is the outcome of a consensus decision reached by members of the CEC. The forecasts published consist of monthly area and production figures for each of the crops at provincial and national levels. Final production estimates are released at the end of the season.

1.2. Inventory of forecasts available, by source

1.2.1. Official national sources

Official crop estimations in South Africa are performed by the CEC, which is administered by the Department of Agriculture, Forestry and Fishery (DAFF). A Crop Estimation Liaison Committee (CELC) has also been established to advise DAFF on crop estimation user requirements. An overview of these main parties is provided in Figure 4.1 below. The other major source of information is SAGIS, which deals with information on producer deliveries, imports, exports and consumption. SAGIS, which does not produce crop forecasts, has the main function of monitoring and regularly reporting on the stock levels of the major commodities.

FIGURE 4.1
Overview of the members of the CELC, CEC, National Crop Estimates Consortium (NCSC) and of the data input providers



1.2.1.1. The role of the Crop Estimate Liaison Committee

At a meeting of the Maize Forum in 1998, it was requested that a working group be established to address crop estimate user requirements. Following this request, the CELC was established, with the National Agricultural Marketing Council (NAMC)[2] appointing the CELC Chairperson and acting as its Secretariat. Any interested party in the industry can become part of the CELC. Currently, its participants include the following institutions: the Chamber of Milling, the Dry Bean Producers' Organization, Grain South Africa, seed companies, the South African Future Exchange (SAFEX), SAGIS, the Chamber of Bakers, the Grain Silo Owners Organization, the South African Cereals and Oilseeds Trade Association (SACOTA), CEC Members and the DAFF. The CELC's function is to issue recommendations upon:

- the role and functions of the CEC;
- the composition of the CEC;
- current methodologies for crop estimation;
- new methodologies for crop estimation; and
- research.

The CELC also has the function of evaluating the results of the CEC's estimates.

The activities of the CELC were accelerated following an unacceptable rise of 12 percent in the CEC's forecast for white maize production in July 1999 compared to the forecast for June of the same year. The consequences of this rise were the following:

- a shortfall had been predicted for white maize from March to June 1999;
- the price on the futures market was therefore kept high;
- millers and processors bought maize at a higher price;
- effectively, consumers paid for this through higher food prices and
- export opportunities were lost.

As a result, the CELC recommended that the DAFF establish a new CEC, comprising members that did not have vested interests in any of the industries. This new CEC began functioning in January 2000.

1.2.1.2. The Crop Estimate Committee (CEC)

The CEC[3], with the Department of Agriculture, Forestry and Fisheries (DAFF)[4] acting as its Secretariat, delivers the official crop forecasts of commercially produced summer and winter field crops (Area, Yield and Production). These are released on a monthly basis for commercial agriculture and once a year for maize produced by non-commercial agriculture. At the end of the season, after a consultation with the CELC, an official crop estimate is published for the commercial production sector.

[2] National Agricultural Marketing Council (NAMC) http://www.namc.co.za/
[3] See http://www.daff.gov.za/daffweb3/home/crop-estimates.
[4] See http://www.daff.gov.za/.

Currently, the CEC consists of the following members, which are all from government and research organizations that do not have any vested interests in the outcome of the estimates:

- 1 Chairperson, from DAFF
- 5 members, from DAFF (acting as Secretariat)
- 1 member from the Western Cape Provincial Department of Agriculture
- 1 member from the Free State Provincial Department of Agriculture
- 1 member from the Eastern Cape Provincial Department of Agriculture
- 1 member from the KwaZulu-Natal Provincial Department of Agriculture
- 1 member from the Mpumalanga Provincial Department of Agriculture
- 1 member from the Limpopo Provincial Department of Agriculture
- 1 member from the Gauteng Provincial Department of Agriculture
- 1 member from the North West Provincial Department of Agriculture
- 3 members of the Agricultural Research Council (ARC); in particular, this entity comprises the Institute for Soil Climate and Water (ISCW)[5] Grain Crops Institute (GCI)[6] and Small Grain Institute (SGI)[7].

Persons having an interest in the buying and selling of grains are not allowed to serve on the Committee. The role of the CEC is to coordinate, control and release official, reliable, objective, accurate, timely, credible and unbiased forecasts of the areas planted and of the production of selected summer grain and winter cereal crops, on national and provincial levels. The summer crops for which forecasts and estimates are computed are maize, sorghum, groundnuts, sunflower seed, soybeans and dry beans. For the purposes of the CEC, white maize is treated as a separate crop from yellow maize; the two are then added to obtain the total for maize. The winter crops for which forecasts are made are wheat, malting barley and canola. The objective of crop forecasts is, first, to provide an indication of the expected area planted; second, an indication of the expected yield and thus production; and finally, a crop estimate at the end of the season to provide an indication of the total crop harvested (actual crop size).

To formulate the forecasts and estimates, the CEC receives data from various sources and reconciles them through a consensus process.

1.2.1.3. The South African Grain Information Service (SAGIS)

SAGIS is a non-profit company, as defined in the Companies Act 2008. It is funded by the Maize Trust, the Sorghum Trust, the Winter Cereal Trust, and the Oil and Protein Seeds Developments Trust. SAGIS is one of the members of the CELC and administers information on producer deliveries, imports, exports and consumption. These are made available via the Internet together with other local and international information, such as prices, stocks, import parity prices, economic indicators, food prices of Statistics South Africa, and climate conditions on a weekly or monthly basis. Market participants – such as grain silo owners, processors, importers and exporters – are statutorily compelled to register with SAGIS and

[5] See http://www.arc.agric.za/arc-iscw/Pages/ARC-ISCW-Homepage.aspx.
[6] See http://www.arc.agric.za/arc-gci/Pages/ARC-GCI-Homepage.aspx.
[7] See http://www.arc.agric.za/arc-sgi/Pages/ARC-SGI-Homepage.aspx.

to submit information. The main aim of SAGIS is to present the amount of whole grain and oilseeds available (stock) in the South African market at the end of each month, and not to make projections. However, this information, in addition to the CEC monthly estimates and forecasts, performs a very important role in the grain marketing decision-making processes of most stakeholders. Thus, SAGIS' mandate is to release national data. Translating this data into a user-friendly format for use by laymen and the emerging agricultural community is the responsibility of authorities such as the DAFF and the Provincial Departments of Agriculture (PDAs), farmers associations such as GrainSA and the National African Farmers Union (NAFU) and economists.

Although SAGIS does not produce crop estimates and forecasts, the actual producer deliveries data released by this service are used in reconciling the final crop production estimate calculated by the CEC.

1.2.2. Other non-official national sources

Many producers' organizations, traders, fertilizer companies etc. calculate their own crop production forecasts, mostly on a national scale. However, these are seldom published. From time to time, the following organizations deliver yield, area or production forecasts to the CEC for consideration:

- Agbiz Grain (http://agbizgrain.co.za/)
- AGKRI (http://agkri.co.za/)
- Agri-businesses
- Bloomberg
- Business Day Live (http://www.bdlive.co.za/)
- Dry Bean Producers' Organisation (DPO) (www.beans.co.za)
- Groundnut processors
- PANNAR (http://www.pannar.com)
- Protein Research Foundation (PRF) (www.proteinresearch.net)
- Reuters
- SAB Maltings (http://www.sab.co.za/sablimited)
- SACOTA (www.afma.co.za)
- SOILL (http://www.soill.co.za/)
- South African National Seed Organisation (SANSOR) (http://sansor.org/)

The NCSC has advocated the use of remote sensing for in-season yield and area estimates. With limited resources, the NCSC explored some options in 2011. Although some progress was made (Frost et al. 2013), an operational stage was never reached. Through the South African Group on Earth Observations (SA-GEO), the CELC could become acquainted with the potential of using remote sensing in crop estimation. In February 2015, this led to a recommendation that a process be started to coordinate the research performed by various academic and research institutions, and to align those efforts to the CEC's objectives. However, resources remain a major constraint to the operationalization of this research.

1.2.3. Other regional/global sources

As far as could be established, the only other regional or global sources are the Specialists from the US Department of Agriculture's Foreign Agricultural Service (USDA-FAS)[8], who travel within South Africa and observe the cropping conditions. These Specialists use Moderate resolution Imaging Spectroradiometer (MODIS-NDVI)[9] satellite imagery to calculate yields that then are used to verify the CEC's output. However, recently, various other parties such as Senwes (agri-business), Unigrain (trader) and Cargill (trader) have also started to travel within the main production areas, to observe and report on the cropping conditions. South Africa also contributes to the GEOGLAM monthly bulletin by submitting crop condition information.

1.3. Release calendars: punctuality and timeliness

Releases

The CEC meets around the 25th of every month. The annual programme and release dates of estimates from the meetings of the CEC, as well as the types of estimates to be made, are published around September each year. For summer crops, eight production forecasts are made on a monthly basis from February to September, and for winter crops, seven production forecasts are made from August to February of the following year. For summer crops, an "Intentions to plant" survey is conducted in October and is followed by a preliminary planted-area estimate in January, while for winter crops this takes place in April and July respectively. At the end of a production season, the crops estimate is finalized; for the summer crops, since the 2013/14 season, this takes place in February of the following year, and for the winter crops in the month of May following the season. The finalization date for the summer crops was shifted from its original date in December to February of the following year to accommodate producer deliveries that take place later in the season. This was decided due to recurring difficulties in predicting these late deliveries, which required readjustment of the final production estimate following publication in December. A summary of the different crop reporting dates against the cropping calendar is available in Annex B4.2.

After each meeting, the secretariat summarizes the forecast and makes it available to the media as from 15:30 on the date of the relevant meeting. The crop estimate is released in two languages, English and Afrikaans. The media release is also published online (at http://www.daff.gov.za/daffweb3/home/crop-estimates). It has been found that the crop estimates are used by a wide audience that includes figures such as traders, farmers, processors, universities, the NAMC, embassies, agricultural companies and international aid agencies.

SAGIS also releases its information to all parties involved and on the SAGIS website on predetermined and approved publication dates (see Annex B4.3).

[8] See http://apps.fas.usda.gov/psdonline/circulars/production.pdf.
[9] See http://modis.gsfc.nasa.gov/.

SAGIS releases the following information:

- **Monthly Bulletin (MB)**: This contains one page per commodity with stocks, producer deliveries, imports, exports and consumption. This is released towards the end of each month, usually one day before the CEC meetings, in English, Afrikaans, Tswana and Zulu.
- **Weekly Bulletin (WB)**: This features a collection of local and international information such as prices, stocks, import parity prices, economic indicators, the food prices of Statistics SA, and weather conditions. The WB is usually released on the SAGIS website by the second working day of every week.
- **Weekly imports and exports (maize and wheat)**: This is usually released on the SAGIS website by the second working day of every week.
- **Weekly producer deliveries (maize and wheat)**: This is usually released on the SAGIS website by the third working day of every week, per grade for maize and in total for wheat.

SAGIS's information is not only used locally for strategic decisions regarding planting intentions, marketing and stocks, but also internationally, by the International Grains Council and by other southern African trade partner countries. Furthermore, as already mentioned, SAGIS's data on producer deliveries are used in reconciling CEC estimates after the end of the production season.

Confidentiality

All CEC members are required to sign a confidentiality clause, in which they commit to not disclose to outside parties any of the information received by the CEC from individual input providers, and to disclose the official crop estimate only after 15:30 on the day of the CEC meeting.

Similar to the confidentiality restrictions on CEC members, SAGIS parties are also not allowed to have any vested interests and must be independent from any party that submits information. SAGIS must collect information from all the parties that are required by statute to register with SAGIS. All information received must be processed and evaluated for correctness and relevancy to ensure the reliability and trustworthiness of the information. Both SAGIS and the CEC members are obliged to treat individuals' information confidentially and to release information only as agreed pursuant to consultation with industry stakeholders.

1.4. How do these different forecasts compare? Purpose, coverage, scale and harmonization issues and accuracy

Although SAGIS was created in 1997, some stakeholders still erroneously believe that SAGIS calculates crop estimates. Officially, the CEC produces forecasts during the season and estimates after the season for the total commercially produced crop, irrespective of weather, including:

- The producer-retained portion on his/her own farm, for animal feed or human consumption;

- The producer grain harvested and delivered;
- The seed that will be used for planting or other purposes.

The estimate excludes any quantities for fodder, silage and/or grazing (i.e. not harvested for grain). Definitions relating to the CEC are set out in Annex B4.4. The CEC also declares the production of the non-commercial sector separately.

SAGIS instead reports on producer deliveries:

- when delivered, commercial structures where grain and oilseeds are handled (commercially stored, imported, exported or processed); grain and oilseeds that are retained on farms for own consumption are therefore not included in this figure
- during a marketing period of 12 calendar months (periods agreed by particular industries), irrespective of whether harvested in the marketing year concerned or in the previous marketing year; and
- regardless of whether the producer is a commercial farmer or an emerging producer.

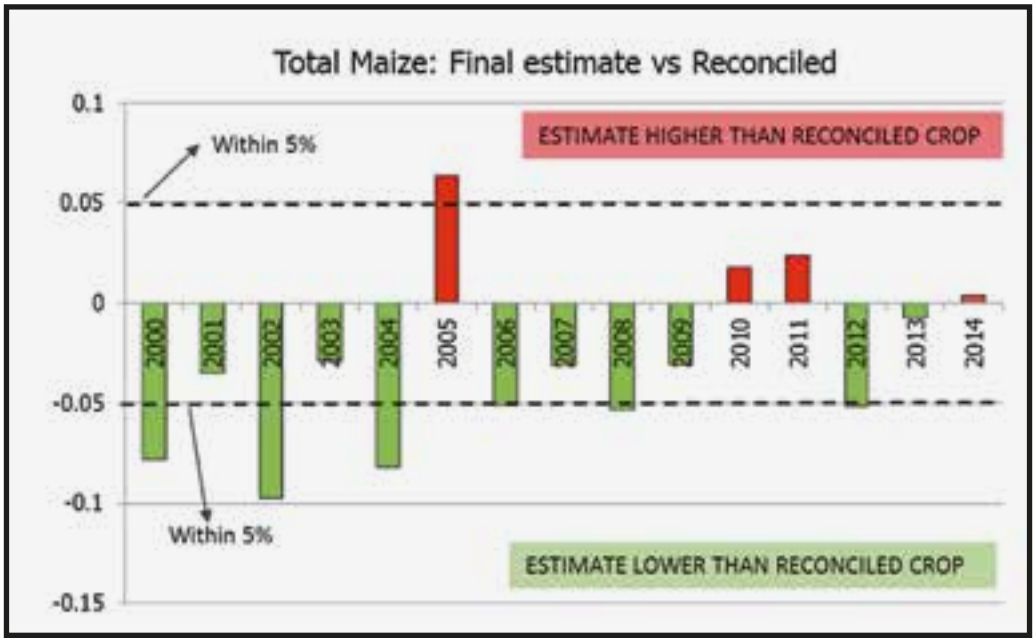
The CEC publishes all figures on a provincial basis. These are subsequently also summarized to national scale. However, intentions to plant and preliminary planted-area estimates are only published on a national basis, except for maize and wheat. SAGIS's monthly and weekly figures are published on a national basis only.

SAGIS breaks producer deliveries down to the provincial level; however, it is not possible to guarantee the point of origin of production. On a provincial level, this may lead to skewed reflection when comparing the CEC's crop forecasts and the deliveries reported by SAGIS.

As mentioned above, the CELC's request to the CEC is "[t]o make available official, reliable, accurate, credible, objective and timely crop estimates", where accuracy is specified as follows: the first to fourth national forecast should be within 8 percent of the final calculated crop, and the fifth to the final estimate within 5 percent of this measure. Objectivity is assured in that there are no vested interests on part of CEC members and that sound statistical methodologies for the data presented to the CEC are followed as closely as possible, without any data manipulation. Timeliness is ensured by the fact that the forecast should reflect cropping conditions at the middle of the month of forecast, and that the information should be released timeously at 15:30 on the day of the relevant meeting. Figure 4,2 below presents a summary of the over/underestimation of the final maize forecast (seventh forecast) compared to the final estimate (reconciled figures) at the end of the season. The accuracy of forecasts since the inception of the new CEC in 2000 is shown in Figure 4.2. For the 15 seasons of its activity, the CEC's estimate was:

- overestimation by less than 5 percent in three out of 15 years
- overestimation by more than 5 percent in one year
- underestimation by less than 5 percent in 5 out of 15 years
- underestimation by less than 5 percent in 6 out of 15 years

FIGURE 4.2
Percentage of over/under estimation of the final maize forecast (seventh forecast) by the CEC since 2000, compared to the final estimate (reconciled figures) at the end of the season



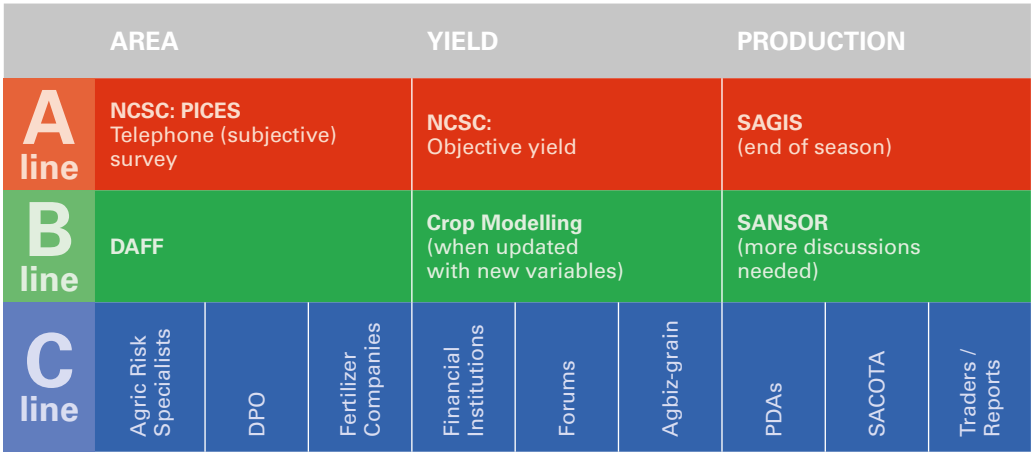
The accuracy of forecasts, since the inception of the new CEC in 2000, has been high in most of the years.

Also on recommendation by the CELC, a decision by consensus was taken to consider the data from input providers, and to ensure that in the forecast decision-making process, the greatest weight should be given to figures in the "A" line, followed by those in the "B" line and finally those in the "C" line (Figure 4.3). The inputs are used as follows:

- A line: to determine the area planted and production/yield
- B line: to evaluate/verify the inputs from the A line
- C line: to evaluate/verify the inputs from the A and B lines

However, this is an arbitrary process that is not linked to any formal statistical procedure.

FIGURE 4.3
Model used to classify the data inputs to the CEC



2. South Africa's national official sources: methodology and practices

2.1. Description of the official yield forecasting methodology

As mentioned above, the CEC meets around the 25th of every month. Officials from DAFF record minutes of the CEC's proceedings. During the CEC meetings, presentations are delivered on the climate and weather conditions for the growing season to date and the current month, and the weather forecast for the rest of the current season. Towards the end of the season, the climate outlook for the following season is also presented. This data gives context to the discussion on yield forecasting.

The CEC's approach is to estimate area and yield at provincial level. Thus, to obtain production, yields are set by province and multiplied with the provincial area estimate. No national yield forecast is set; rather, this is obtained by dividing the sum of the provincial productions by the sum of the provincial area estimates.

The data inputs received from the various data suppliers for the yield forecast are summarized in Excel spreadsheets prior to the meeting, and distributed to the CEC members during the meeting.

The estimation process is carried out by crop for each province for the area estimate; then, the yield is estimated. The production per province for each crop is obtained by multiplying the estimated area with the estimated yield.

The CEC members debate the inputs received from the different data suppliers for each specific province and crop and then set a forecast/estimate for the yield. The provincial official of each relevant province presents the crop conditions prevailing in the province for specific crops, as well as a forecast/estimate for that crop yield for the province. DAFF contributes

the results from a subjective telephone/post survey of a number of willing farmers (called cooperators) for individual crops in a given province. The other CEC members are free to present views at any time during the estimation process. The yield of a specific crop for a given province is then agreed upon by consensus, based on a convergence of the available evidence and confirmed by the Chairperson. The areas planted for a specific crop for all provinces are then added to obtain a national area-planted forecast for that crop. Then, the province production totals are added to obtain the national production forecast for that crop. The national yield is obtained by dividing the total area (sum of provinces) by the total production (sum of provinces). These procedures are repeated for each crop. The official forecast is then summarized and made available to the media as from 15:30 on the date of the relevant meeting.

After the production season has been completed, the final (calculated) size of the crop is determined. The final production estimate figures are reconciled using the actual SAGIS delivery figures as the basis for the calculations. The final crop size (production) represents the available grain during a year from 1 March to 28 February of the following year. Early deliveries (April and May), possibly from the previous season, are included and provision is made for grain yet to be delivered from the current production season (January and February) – these are termed late deliveries. Retentions of grain on farms are determined by means of surveys conducted by DAFF and the NCSC (by post and telephone), and are also added to the SAGIS delivery figures to calculate the total commercial crop figures.

The final crop estimation process can be summarized as follows:

TOTAL COMMERCIAL CROP = DELIVERIES (including early and late) + RETENTIONS ON FARM

↓ ↓

SAGIS **(surveys undertaken by DAFF and NCSC)**

The final (calculated) crop is then presented to the CELC meeting for inputs and verification before being officially announced by DAFF.

2.2. Relevant practices for data collection

Data is received from different organizations and institutes as inputs to the CEC meetings. This does not necessarily mean that these organizations are members of the CEC. Inputs are usually received by fax, e-mail or telephone. Not all organizations present data for all meetings.

The ARC, DAFF, PDAs and the NCSC are the main data suppliers for the CEC meetings.

The NCSC was formed in 2001 and supplies the CEC with primary crop estimate data. The NCSC is a public-private sector consortium comprising the ARC, SIQ (Pty) Ltd. and GeoTerraImage (Pty) Ltd. The NCSC developed the methodology employed for crop yield forecasting. This methodology includes a telephone survey of a sample of farming enterprises, drawn from a

point frame-based sample; the selected sample point is connected to the contact details of the farming enterprise. An in-field objective yield assessment is also part of the methodology and is described fully in Section 2.2.1.3 below.

2.2.1. Methodologies operationally used by the National Crop Statistics Consortium (NCSC)

This section details the methodologies used by the main input data suppliers to the CEC for yield.

2.2.1.1. A stratified point-based sample frame for telephone or personal interview surveys

In the early 2000s, with assistance from the USDA's National Agricultural Statistics Services (NASS)[10], the NCSC developed a crop yield, area and production estimation system similar to that used by the USDA. While the USDA's system is based on an area frame and a list frame, the South African system was developed using a point frame approach. This system was first implemented with the summer crops for the 2001/02-production season, and has been basically used ever since for both summer and winter seasons. However, improvements and local adaptations from lessons learnt have been incorporated over time. For the first summer season, all nine provinces were surveyed. This proved to be unsustainable due to the high costs and resources required for the field survey work. It was therefore decided that only four provinces – Free State, Gauteng, Mpumalanga and North West – would be sampled for the subsequent summer crop surveys, and Western Cape, Free State and Northern Cape provinces for the winter crop surveys. These provinces generally account for over 85 percent of the total production in any season. However, since 2013/14, DAFF decided to omit statistical surveys (areas planted through the Producer Independent Crop Estimates Survey (PICES) methodology and the objective yields) in respect of winter crops for the Northern Cape Province. The reasons are the following:

- Almost all of the plantings for the Northern Cape are irrigated;
- The area planted with wheat is relatively stable and has ranged between 38,000 and 42,000 ha for the past five years;
- The yields range between 6.5 and 7.5 t/ha for the past few years;
- The inputs obtained from other data providers, such as the Departments' sample of producers and the PDA representatives, are considered reliable and accurate;
- The winter crop survey for the Northern Cape requires approximately 10 percent of the budget;
- Therefore, it was decided to use these funds to collect the maize planted area in the non-commercial sector in the various provinces, to improve the accuracy of that data.

The NCSC has developed generic area sampling frames that can be used for a number of agricultural surveys. South Africa was stratified into a number of strata according to cultivation intensity and different land uses. The strata are then sampled every season with

[10] See http://www.nass.usda.gov/.

a point sample frame. Three types of surveys are conducted: (i) an area-planted survey, (ii) a telephone farmer-expected (subjective) yield survey and (iii) a point-based objective "in-field" yield survey. From 2001/02 to 2004/5, this was the method used for yield and area estimates (see Section 2.2.1.2 below). However, due to the increase in producers' refusals to take part in the survey, the PICES methodology was developed and adopted to ensure more accurate area estimates (see Section 3.1.1 below).

The telephone yield survey is carried out in January/February for summer field crops and August for winter field crops. The survey is conducted by randomly selecting a number of points from the dominant cultivated strata over the relevant provinces. These points are then used to identify the farming enterprise in which they are located. The enterprise's contact details are obtained, and the enterprise is then contacted for a telephone survey in which expected yield data and area planted are retrieved. The results of this subjective telephone survey are presented to the CEC in February/March for summer field crop yields, and August for winter field crop yields. The same sample is also used to obtain actual final yield and grain retention on farm data that are used to calculate the final crop estimates in February (for summer field crops) and May (for winter field crops).

System design

Stratification

The aim of stratification is to identify, on a national basis, which areas do and do not contain cultivated lands and use this information as a sampling framework to select the optimal sample points for data collection. Medium-resolution (Landsat) satellite imagery is used as the basis for stratification.

The process of developing the advanced stratification framework involves two basic stages:

- Updating existing land-cover data using recent Landsat imagery, to create up-to-date "exclusion masks" and spatially define all areas within which the probability of finding cultivated lands is negligibly low (e.g. urban areas, forest plantations, etc.)
- Classifying the remaining areas containing cultivated land into three density strata, based on cultivated field patterns within a 5 km x 5 km classification unit.

The two components are then merged to create a single national coverage that first highlights all areas that – in terms of either land cover or land use – did not feature any probability of commercial grain-growing areas, and second, that subdivides all areas containing commercial grain cultivation activities into three density strata, according to the intensity of local farming activities within a 5 km x 5 km unit. This coverage then became the basic stratification for the sampling framework used to guide the distribution and location of field sample points, and thus to improve overall statistical representation (Figure 4.4).

The stratification classes used are the following:

Agriculture classes:

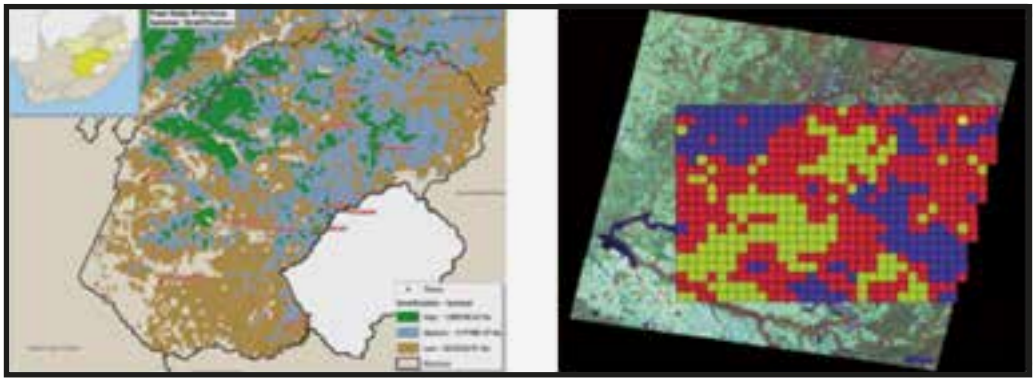
1. Cultivated greater than 80 percent
2. Cultivated between 30 and 80 percent
3. Cultivated 1 to 30 percent
4. Irrigation schemes
5. Non-commercial/communal area
6. Sugarcane
7. Horticulture/viticulture
8. Plantations
9. Smallholdings/peri-urban
10. Rangeland
11. Rangeland

Non-agriculture classes:

12. Urban (residential/commercial – no cultivation)
13. Conservation, mines & rock (national parks, mines, bare rock)
14. Water bodies

Classes 6 to 9 are collapsed into a single class to reduce the number of sample points required for classes in which the probability of finding cultivation of grain crops of interest is low. The collapsed stratum is then sampled. The non-agricultural classes (12 to 14) are not sampled because the probability of finding the crops of interest therein is very low or negligible.

FIGURE 4.4
Stratification for summer crops



The summer crops are stratified in high, medium and low strata based on field densities in a 5 km x 5 km grid. The stratification is used to guide the distribution and location of the field sample points, and thus to improve the overall statistical representation.

Sample frame

To set up the sample selection, a regular point grid of 225 m x 225 m is used and overlaid on the stratified map of South Africa. The number of points required per stratum and per province is calculated so as to provide a CV of approximately 10 percent per province and around 5 percent nationally. The sample of points for each estimate is then selected from the grid using systematic random sampling (Cochran 1977). This is done by stratum and province using GIS technology. These randomly selected points are then used by field or telephone interviewers to collect the basic data required for the statistical calculation of the crops. To relieve respondent burden, approximately 20 percent of the points are replaced on an annual basis.

2.2.1.2. Yield surveys using the telephone interview or field point frame (TAFSS)

The data collection process

Field data can be collected either by visiting the site where the point is located or by means of a telephone interview, depending on the type of survey procedure followed as per the relevant contract for the season. Telephone or field interview area and yield survey (TAFSS) questionnaires are designed for the survey, to collect information for the farming enterprise in which the point is located. If the point is located on a farming operation, information for the field (if the point is located on a field with a crop of interest) and the whole farming operation is collected. All enumerators undergo prior extensive training. The trained interviewers, the majority of whom are farmers themselves, visit the points to collect the data. The interviewers are contractually bound to refrain from disclosing any information concerning individual farms to any third party.

The interviewers navigate to the points by means of a handheld Global Positioning System (GPS) and standard 1:250,000 map sheets. Overlaid on the standard map sheets are the locations of the points to be visited, as well as an indication of the optimum (shortest) road transect to follow to visit a number of allocated points. The interviewers should attempt to abide by the prescribed farm access control protocol and obtain permission to visit the point. The point and the field should then surveyed, the farmer interviewed and the data captured on the field survey questionnaire.

The data capturing process and quality control

A computer-based data capture and storage system has been developed and is used to easily enter field data into the system, as well as to perform essential quality control on the interviewer's data input. This ensures that time is not wasted on correcting basic survey errors but is rather focused on data analysis and quick reporting. To make sure that the survey data is as relevant as possible, the survey and the reporting of the results must be completed in as short a time frame as possible. By using the Internet, the data is collected remotely (in the field or from other offices) and sent to a centralized server. This ensures data integrity and relevance at all times.

Data analysis and expansion

A point that represents a farming enterprise in which crops of interest may be found is said to be representative of typical farms within that stratum (and within a province). Therefore, this point actually represents other typical farms of that nature within the stratum. To calculate what each selected point represents, the stratum area is divided by the number of points in the same stratum. This yields an expansion factor that is multiplied by a factor of the crop area divided by the farm area (thus obtaining the ratio of crops to total farm size).

Three different estimates may be derived, namely a) the point-based estimate, b) the field-based estimate and c) the farm operation estimate. The estimates are generated for provincial and national cropped areas and production. The farm-based estimates deliver the most reliable results with the lowest coefficients of variance (CV). The results are then compared with the required coefficient of variances as stipulated in the contract, to determine whether the objectives were met. The results obtained are then presented at the CEC meetings by province.

2.2.1.3. The Objective Yield Survey (OYS)

OYSs derive yield by taking in-field measurements. The South African OYS for white and yellow maize and wheat is complementary to the TAFSS; the OYS locations to be sampled are selected from the TAFSS in which crops of interest were found. OYS samples are selected within each province with a probability proportional to size (PPS), making it a self-weighting sample. This makes it possible for fields that are large and thus have a large expansion factor to be selected for more than one sample. Enumerators (20 for the maize survey and 15 for the wheat survey) visit the selected fields and record background information on planting dates, cultivars, growth stages, and geographic coordinates. This is followed by measurements of plants and fruit on randomly selected sites within the field, following strictly established procedures. All enumerators are selected and engaged under a contract with the ARC. Prior to each survey, enumerators are given hands-on practical training.

For maize, initially (from 2001/2002 to 2004/2005) three surveys were undertaken to sample the same locations in April, May and June. However, the variation in the yields obtained from the survey between months was not acceptable. Thus, it was decided to sample only once, when the maize had reached physiological maturity. The OYS sampling procedure is subject to producers granting enumerators access to the fields. If many producers refuse, the survey's statistical integrity may be compromised. A disadvantage of the OYS system is its high operational cost. At least 5 percent of all points surveyed are re-surveyed by ARC personnel for quality control purposes. The field survey questionnaires also undergo a quality check against the digital database. The field survey progress is monitored on a daily basis to evaluate enumerator performance and to establish whether any delays may occur; various support lines are available for the duration of the project. NCSC staff members are trained to deliver support for this purpose.

Methodology for Maize

The OYS for maize is undertaken annually, under the supervision of the GCI. For the maize OYS, 700 sampling locations (fields) within the provinces of Mpumalanga, Free State and the

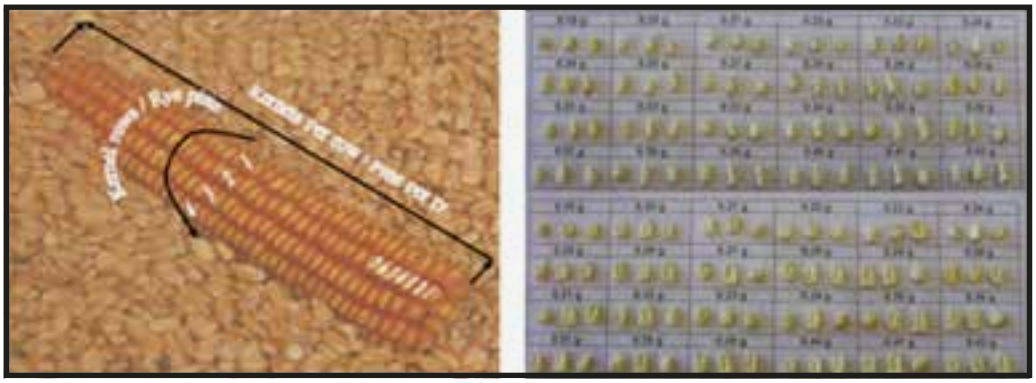
North West are allocated proportionally to the area of cultivation for white maize and yellow maize (either dry-land or irrigated), based on the PICES area figures released in February of each season. A prerequisite is that at least ten locations for irrigation must be sampled. The OYS is undertaken annually in April in Mpumalanga and in May in the Free State and North West provinces, due the differences in crop maturing. Enumerators visit all identified locations and follow the Rapid Assessment Sampling Methodology. The fields to be sampled at each location are identified based on a random numbering system. The first location within the field is also randomly selected, being given random numbers that must be paced along and within the field. From this first in-field sample, the other four samples are also randomly selected, pacing 30 paces in one direction and other 30 perpendicular to these. For each of the five in-field sampling locations, 10 m of one row is marked. All ears within the 10 m row are counted (Figure 4.5a below). The first 11 ears occurring in the row are selected. These ears are sorted and arranged according to their length, from short to long (Figure 4.5b below). The middle ear (median) is selected for yield determination. If the maize is not yet physiologically mature, the number of kernel rows and the number of kernels per row on each ear are counted (Figure 4.6a below). To derive kernel weight, some kernels are selected and compared to a chart depicting kernels of different mass (Figure 4.6b below). If the maize is physiologically mature, kernel weight is determined by shelling and weighing. The moisture content for each ear is also determined using a moisture meter. If the maize has been harvested, the farmer is questioned on the field's yield. At each of the five in-field sampling locations, GPS coordinates are captured. Row width is determined by measuring across six rows (see Figure 4.5c below). All the information is captured in a spreadsheet and verified, outliers are identified, and using a regression model, adjustment for bias is made. Yields are adapted to reflect farmer yields based on a study funded by Maize Trust[11]. Because the selection of sampling points is proportional to size, yields are averaged by province, for dry-land and irrigated points respectively. Using the PICES area, a weighted average yield per province is calculated. The results are presented to the CEC during the survey month. After the surveys, a full-length report is compiled and presented to the CEC Secretariat in June.

FIGURE 4.5
Objective Yield Survey for maize

a) Measuring a 10 m row and counting the number of ears. b) Determining the median ear to be sampled. c) Measuring the row width.

[11] See http://www.grainsa.co.za/the-maize-trust:-custodian-of-the-maize-industry.

FIGURE 4.6
Kernel determination



a) Methodology for counting kernel rows and kernels per row. b) Chart depicting average weights of kernels according to size

Methodology for Wheat

The wheat OYS is undertaken annually by the SGI. For the wheat OYS, in determining the field to be sampled and the in-field sampling locations, a method similar to that adopted for maize is followed. However, for wheat, only two in-field samples are taken. Previously, 660 fields were sampled by 15 enumerators in the Western Cape, the Free State and the Northern Cape. However, as from the 2014 season, the Northern Cape was discontinued (see Section 2.2.1.1 above). If the rows are visible in a field, the row width is measured over three rows. The number of ears in three 50-cm parts of a row parallel to one another is counted. Then, the first ten ears per row are selected and the number of grain kernels are counted (Figure 4.7a below). If the field is broadcast sown (i.e. without rows), a 70 cm x 70 cm square is used and is then divided into thirds (9 blocks). The number of all the ears in each block is counted. Three sub-blocks are identified and within each, 10 ears are randomly chosen to obtain the number of kernels per ear (see Figure 4.7b below). This leads to 60 ears being counted per in-field sampling location, irrespective of rows or broadcast. Using a predetermined average kernel mass, the yields for each location are calculated. These are subsequently summarized to provincial level and presented to the CEC. Average bias adjustments per province are determined and implemented by the CEC as required.

FIGURE 4.7
Methodology for determining number of ears in a wheat field

a) rows are visible and b) rows are not visible

2.2.1.4. Retention on Farms

To determine the actual crop size, at the end of the season an estimate of the retention of e.g. maize required is included. Independently from the DAFF survey (see Section 2.2.2.1 below), the NCSC, through the SIQ, undertakes a telephone survey and contacts various classes of producers. This information then is collated and is made available to the secretariat.

2.2.2. Department of Agriculture, Forestry and Fisheries (DAFF)

2.2.2.1. Methodology used for the commercial sector

DAFF makes use of a post, e-mail and telephone survey to estimate the area and production of summer and winter crops. Data on the area planted and the farmers' opinions on their expected production are collected. In other words, the farmers are questioned on their current experience and their opinion on the season's outcome. However, depending on the market and due to collective uncertainty levels, these results are often biased; DAFF's input is thus relegated to the "B" line priority in Figure 4.3 above.

The area planted is estimated at the beginning of a season, while the expected crop is forecasted monthly throughout the growing season (for summer grain, from February to September; for winter cereals, from August to February). DAFF sends its questionnaires to a non-probability sample of cooperators (issuing a total of approximately 1,700 summer and 1,400 winter questionnaires).

The methodology relies upon the basic principle of "change from the previous season". To estimate the area planted for a season, the areas planted by the respondents for the current season are compared with their areas planted for the previous season by magisterial district or province. The calculated percentage of increase or decrease indicated by the data gained from the respondents is applied to the total area planted per district of the previous season, to obtain an estimate of the area planted for the current season.

The respondents' estimated production for the present month is used, along with their declared area planted, to obtain an average yield for all respondents in a given magisterial district or province. This information is supplied to the CEC at its monthly meetings.

Before 1997, this data was tested against the size of the full crop produced the previous year, which was obtained from the former Marketing Boards. This resulted in a much more accurate figure. However, there is currently a lack of benchmark data, because SAGIS deliveries only become available five to six months after the start of the marketing year.

The weakness of DAFF's methodology is that an error in the estimated area of the previous year is carried over to the present year. Furthermore, the response to surveys conducted by post is often poor.

To determine the retention of grain on farms, DAFF uses a maize and a wheat utilization postal survey at the end of the production season. Information on the quantities of maize and wheat retained on farms to be used for own consumption (human consumption, farm feed and seed) can thus be obtained.

2.2.2.2. The methodology used for the non-commercial agricultural sector

For the purposes of the CEC, the non-commercial farming sector is defined as comprising the farming operations in which output is produced primarily for consumption by the farmers and their family members (households), and not for cash sale. Data on non-commercial agriculture is received from the PDAs at the beginning of the production season. The PDAs obtain the data from their extension officers in the different regions of the provinces. However, this data is often lacking in reliability and accuracy. Still, it is critical for food security management and intervention decisions. DAFF has requested the NCSC to further develop the existing crop estimates methodologies to enable the estimation of areas planted for summer field crops in the smallholder farming areas in South Africa.

2.2.2.3. Efforts to improve DAFF's methodology

Efforts have been made by DAFF to improve the response rate of the surveys conducted by post. Farmers who do not respond in time are contacted via telephone to obtain the necessary information. DAFF has also set up a list of all the farmers who prefer to respond via e-mail or fax, and has contacted these farmers through the preferred medium. Investigations into using mobile device-based responses to strengthen response rates have been undertaken. However, this option has not proved viable due to the high costs of application development and the absence of hardware to host such a service. As an alternative, producers are contacted by SMS and requested to submit their crop estimates information in this way. The response obtained through this medium has proven to be positive. The recruitment of new respondents is continuously undertaken and communication channels such as the media, agricultural shows and farmer days have been used to promote participation in the crop forecasting process.

2.2.3. Provincial Department of Agriculture (PDAs)

The members representing the PDAs from the nine different provinces use different methods to determine production within their respective provinces. Provincial extension officers assess local conditions and engage in direct consultations with farmers and farmer study groups. They also make their own observations regarding weather conditions, crop conditions (phenological stages), crop pests and diseases. The PDA representatives on the CEC are usually experts on crop production within their own provinces, and have a network of contacts from which they can obtain information on areas planted and yields. This network may include cooperatives, seed companies, producer organizations and large-scale commercial farmers. Based on the information gathered, a subjective area and yield forecast is provided.

2.2.4. The Agricultural Research Council (ARC)

2.2.4.1. The Institute for Soil, Climate and Water (ISCW)

The ISCW is responsible for presenting the weather conditions and an outlook for the rest of the season at the beginning of each crop estimates meeting. The presentation is based on the Umlindi Report[12] (Umlindi is the Zulu word for "watchman") and consists of various elements, depending on what is of interest at a given point in time.

An overview of the conditions during the previous weeks over the whole of South Africa are mapped out. These conditions include:

- **Rainfall**:

a. Actual rainfall over a certain interval of time (e.g. a month)
b. Rainfall over certain periods expressed as a percentage of the long-term average
c. Total rainfall difference over a certain interval of time compared to a previous season
d. Rainfall deciles used to express the ranking of rainfall for a specific period, in terms of the historical time series. The rainfall maps combine the inputs from 450 automatic weather stations of the ISCW's weather station network, 270 automatic rainfall recording stations from the South African Weather Service (SAWS), satellite rainfall estimates from the Famine Early Warning System (FEWS)[13] and long-term average climate surfaces developed at the ISCW.

- **Temperature**: The lowest and highest temperatures over a given interval of time are collected, to indicate extremes that can be linked to different development phases of the crops of interest. Data from the ISCW and SAWS weather station networks are used for these products.
- **Standardized Precipitation Index (SPI)**: The Standardized Precipitation Index (SPI) (McKee et al. 1993) was developed to monitor the occurrence of droughts from rainfall data. The index quantifies precipitation deficits at different time intervals (three-month, six-month, 12-month and 24-month) and therefore also the severity of

[12] See http://www.arc.agric.za/arc-iscw/Pages/Newsletters.aspx.
[13] Also, see the Early Warning and Environmental Monitoring Program (EWEM), http://earlywarning.usgs.gov/.

droughts. It provides an indication of rainfall conditions per quaternary catchment (in this case), based on the historical distribution of rainfall. This indicates which areas suffer from drought or present wet conditions.

- **Soil Saturation Index**: The soil saturation index indicates the relative soil water content. The modelling of soil moisture is performed by the University of KwaZulu-Natal (UKZN) Applications and Hydrology Group. Supported by the World Meteorological Organization (WMO), the system and algorithms developed by the UKZN have been replicated at the ISCW, where the developing archive will be used in expanding the suite of drought monitoring products provided in near-real time.

Data from the operational ISCW's Coarse Resolution Imagery Database (CRID) project includes data from the Geostationary METEOSAT Second Generation SEVIRI (Spinning Enhanced Visible and Infrared Imager) sensor. The 1-km and 250-m resolution Normalized Difference Vegetation Index (NDVI) data and derivatives from the SPOT VEGETATION, PROBA-V and MODIS missions are used for the following products:

- NDVI: NDVI images describe the vegetation activity. A decadal NDVI image shows the highest possible "greenness" values that have been measured during a ten-day period.
- Standardized Difference Vegetation Index (SDVI): the SDVI is the NDVI's standardized anomaly (according to the specific time of the year).
- Percentage of Average Seasonal Greenness (PASG): An expression of the cumulative NDVI (representing cumulative vegetation activity) for a specific period, expressed as a percentage of the long-term average for the specific period. It provides an indication of overall performance during a growing season.
- Vegetation Condition Index (VCI): The VCI is an indicator of the vegetation cover's vigour as a function of the NDVI minimum and maximum encountered for a specific pixel and for a specific period, calculated over the period of data availability. The VCI normalizes the NDVI according to its changeability over many years, and results in a consistent index for various land cover types. It constitutes an effort to split the short-term weather-related signal from the long-term climatological signal as reflected by the vegetation. The VCI has been found to be a better indicator of water stress than the NDVI.

An overview of significant weather conditions during the coming period (sourced from the output of Global Coupled Climate Models published online) is also presented and includes:

- **Sea Surface Temperature (SSTs)** from the NOAA Climate Prediction Centre[14]
- **El Niño-Southern Oscillation (SSTs and SOI)** from the Australian Bureau of Meteorology[15]
- **El Niño-Southern Oscillation (Probabilistic forecast)** from the CPC ENSO outlook[16]

[14] See http://www.cpc.ncep.noaa.gov.
[15] See http://www.bom.gov.au.
[16] See http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/.

- **Southern Annular Mode (SAM)** from the Annular Mode Website[17], and the
- **Pacific Ocean Equatorial SST Anomaly**

The overview of expected conditions over South Africa during the next few days and seasonal outlooks are also presented. These conditions include:

- Precipitation forecasts from two sources:

a. the short-term outlook from the Center for Ocean-Land-Atmosphere Studies (COLA) and Institute of Global Environment and Society (IGES)[18] and

b. seasonal forecasts by the South African Weather Service[19].

- Temperature forecasts from two sources:

a. the short-term outlook from COLA and the IGES; and

b. seasonal forecast by SAWS.

The ARC-ISCW also provides qualitative information on a monthly basis for maize and wheat by province to the GEOGLAM[20] (Group on Earth Observations Global Agricultural Monitoring) initiative.

2.2.4.2. The Grain Crops Institute (GCI)

2.2.4.2.1. Crop modeling

Crop models in some form have always been part of the maize crop estimates system. The initiative to use process-based models for large area estimates began in 1982/83 by evaluating the South African PUTU model and the Crop Environment Resource Synthesis (CERES)-Maize model (De Vos and Mallett 1987). De Vos and Mallett (1987) and Prinsloo and du Toit (1996) found the CERES-maize model to be more accurate at this scale. Since 1995, CERES maize has been used as a model in the drought monitoring and forecasting of maize yields in the Free State Province (van den Berg and Potgieter 1997; van den Berg and Manley 2000). Since 2001, the CERES-maize model is used to estimate maize yields for six to eight provinces (Durand and du Toit 2007). Over the years, the method has been refined. Once, the modelling was performed for 8,650 locations with known soil properties, using the closest climate data point where only rainfall is measured; today, a more spatially representative system based on field boundary delineation is used. For the years from 2006 to 2009, a maize crop field-level land cover consisting of approximately 130,000 potential maize fields was developed using satellite imagery, PICES (see Section 3.1.1 below) and crop type classification (Section 3.1.3 below). This approach honours the scale of a homogeneous plot at which the Decision Support System for Agrotechnology Transfer (DSSAT)[21] crop model was developed, but takes into account district-level yield variation, since the whole population of maize fields within a district is modelled.

[17] See http://www.atmos.colostate.edu/ao/index.html.
[18] See http://Wxmaps.org.
[19] See http://www.weathersa.co.za/home/seasonal.
[20] See http://geoglam-crop-monitor.org/.
[21] See http://dssat.net/about.

Crop management data, such as row spacing, plant population and planting dates, were derived from OYSs (see Section 2.2.1.3 above). The country was divided into two types of zone, i.e. those above and those below 500 mm of rainfall per annum. From OYSs, over a six-year period (2008-2013), approximately 5000 samples (mainly within the Free State, North West and Mpumalanga provinces) were used to calculate the proportion of fields with certain row widths, planting dates and plant populations. The same proportion calculated was used to assign the management strategies to all the fields within a province and rainfall zone using the "Sample Features" command of the Geospatial Modelling Environment (Version 0.7.2.1) (Beyer 2012). Fertilization was based on the average modelled 50-year yield potential of each field, using climate data from the Quaternary Catchment database (Schulze et al. 2007).

The soil properties required for crop yield modelling were derived using the identified soil series suitable for maize production within land types (MacVicar et al. 1974), based on a Shuttle Radar Topography Mission (STRM) digital elevation model (92 m). This was derived by eliminating soils with mechanical restriction, a depth of less than 400 mm and a clay content greater than 50 percent within each Terrain Unit (TU) (scale of 1:50,000). To determine the soil properties for each field, the weighted averages of the soil properties were first calculated for each TU. Second, the soil properties in each field were calculated on the basis of the percentage representation of each TU within a field, using zonal statistics (GIS). This resulted in each field having a unique soil description. The drained upper limit (DUL), lower limit (LL) and saturation (SAT) were derived from pedo-transfer functions based on clay content and bulk density, drainage rate, the evaporation limit and organic carbon used similar pedo-transfer functions developed for the South African Agricultural Catchments Research Unit (ACRU) model (Smithers and Schulze 1995; Hutson 1984). Runoff was based on a slope and hydrological grouping (Schulze et al. 1985).

As minimum climate data inputs, the crop model requires rainfall, minimum and maximum temperature and solar radiation. Rainfall data is obtained from participating agri-businesses and the ISCW database, and covers approximately 500 stations. However, a major limitation on crop model inputs is temperature and solar radiation. These may be derived using the WGEN weather generator embedded in the DSSAT (Richardson and Wright 1984). The WGEN calculates the daily missing variables from a stochastic model on at least five years of actual climate data. For this purpose, the 50-year quaternary catchment database is used. GIS is used to assign each of the 500 rainfall stations a historical database as well as the nearest rainfall station to each field (Thiessen polygon).

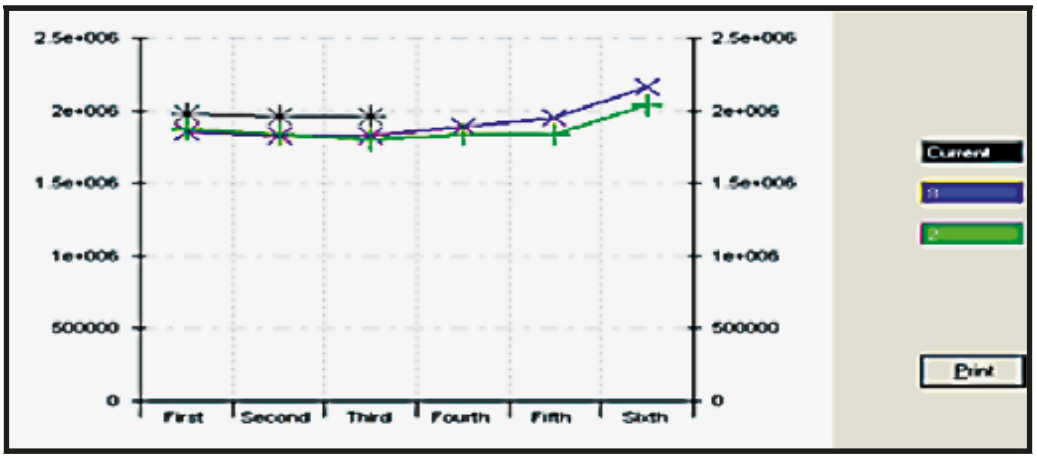
For crop estimates, the actual rainfall is known until the end of the month before the estimate; however, the crop model requires climate data until the end of the season. The tool developed and integrated into the system to forecast the rest of the seasons' climate is the so-called weather analogue program (du Toit et al. 2001; du Toit and du Toit 2002). This program identifies the closest analogue year from a historical database based on the rainfall received from July (winter before the cropping season in South Africa) to the relevant point in time, i.e. the end of January for the February forecast. The whole climate data set of the historical database is added to the current climate data, to obtain the entire season's climate data (July to June) that is available to the crop model. The longer the historical component, the greater the probability that a like year can be found. The historical data set used for the maize yield estimates is the quaternary catchment database (Schulze et al. 2007).

To facilitate the running of such a large number of simulations, the QUAD-UI and DOME functions developed in the Agricultural Model Improvement and Inter-comparison Project (AgMIP)[22] project are used. The approach of modelling fields allows for a flexible system in which yields can be summarized to the scale required, i.e. watershed, district or province. The yield estimates derived from crop modelling are presented to the CEC on a monthly basis, from February to May. Since this methodology is still in a developmental phase, it was assigned to a "B" level use (see Figure 4.3 above).

2.2.4.2.2. Trend analysis

Using analogue technology, the GCI developed a trend analysis software in 2000 to assist the CEC in improving maize crop estimates, by indicating over- or underestimation trends. To establish a trend, the statistical software requires at least three estimates for a given season. Using the analogue process, two historical seasons following the same trend as the current season are identified from a historic database (D-index) (see Figure 4.8 below). For each of the two seasons, the average is calculated using the current production value and the reconciled value of the historical season. An average between these two values is then calculated. The calculated production is subsequently compared to CEC previous meetings on production, and over- or underestimation trends are presented to the CEC. Using the current seasons' area, it is possible to calculate a yield. This data is considered a so-called "C-line" data input (see Figure 4.3 above), which means that the CELC has requested the CEC to use the figures only as an evaluation and verification tool.

FIGURE 4.8
Graphic description of the trend analysis



The GCI developed a trend analysis software to assist the CEC to improve maize estimates.

The GCI is also part of the NCSC and is primarily involved with the OYS for summer grains (maize).

[22] See http://www.agmip.org/.

2.2.4.3. The Small Grains Institute (SGI)

The SGI is in constant contact with the major winter grain-producing areas and, on the basis of decades of experience, compiles its estimates in accordance with the prevailing conditions for submission to the CEC. The SGI is also part of the NCSC and is primarily involved with the OYS for winter grains, i.e. wheat.

2.3. Relevant practices for data sharing and analysis, harmonization and integration

Both yield and area data are collected under contract (non-disclosure agreements) with DAFF. Thus, DAFF is the owner of the data. Geolocated data relating to individual farmers has strategic business value and is regarded as sensitive data; therefore, DAFF does not make it readily available in the public domain. DAFF releases data that is more than one year old (i.e. relates to the previous season) in summarized form, upon request. Data sharing can take place within the consortium, if the purpose is to enhance the current crop estimation system by means of research.

2.4. Human, financial and technical infrastructure

The PDA representatives' contribution to the crop estimation process depends on the capacity that exists within a specific province in terms of finances, networking and technical skills and experience. DAFF has undertaken to improve capacity relating to crop forecasting in the provinces by addressing training needs and stressing the importance of crop forecasting to PDA management. If the provinces lack the financial resources necessary for attending CEC meetings, DAFF helps to provide the travelling costs.

The NCSC is a collaboration between semi-governmental and private institutions. The presence of private partners allows for a certain degree of flexibility in the system, which would not be possible if only government agencies were involved. The NCSC funding derives entirely from DAFF. The NCSC budget leaves very little room for research, because most of the funds are allocated to operational functions. From 2008 to 2012 (thus, for four years), the Maize Trust has funded a small research-orientated project to strengthen the crop estimates system.

2.5. Institutional structure and sustainability

The contract between the NCSC and DAFF is re-negotiated annually, and specific objectives and outputs are discussed. The ISCW is the NCSC's lead agency and is responsible for the project on "Development and operationalization of a statistically sound crop estimation methodology to estimate area-planted for summer and winter field crops, as well as to objectively forecast yields in South Africa." The SIQ and GeoTerraImage are two Small, Medium, and Micro-sized Enterprises (SMMEs) that deliver most of the operational services within the NCSC. The ARC provides the operational yield estimates.

2.6. Innovation and integration with regional/global level initiatives

The SA-GEO Agricultural Community of Practice is active in the GEOGLAM and has an active Joint Experiment of Crop Assessment and Monitoring (JECAM) site. However, a lack of research resources constrains the level of activity in these initiatives. The ARC, with the CEC's approval, contributes to the GEOGLAM bulletin each month. South African researchers are also involved in the AgMIP crop modelling project.

3. Linking up with crop production forecast: the practices followed by the South Africa's official national sources

3.1. Which area data is used? Description of the methodology

The CEC uses two sources for area estimations. The first is the DAFF survey (post or e-mail). This is used to determine the intentions to plant and to obtain a preliminary area estimate. For the remainder of the forecasting season, it is used to underlie the PICES, which is the second main source that must be acknowledged by the CEC. The CEC estimates the area planted, and not the area harvested. For summer crops, the first area estimate is made in January and may be adjusted in February and March if there is sufficient evidence to support a revision. Otherwise, the area is rarely adjusted during a season. Most adjustments are made in the yield estimate, in relation to the production estimate. For winter crops, the first area estimate takes place in July and the area may be adjusted again in August.

3.1.1. The Producer Independent Crop Estimates System (PICES)

PICES is a method that was developed by NCSC and is used to estimate the areas planted to summer and winter grain crops in South Africa. Originally, it started as a pilot project in Gauteng in the 2004/05 summer season. PICES was developed because, although the percentage of refusals was small with the Subjective Area Frame System, it was discovered that there was an increasing tendency of farmers to refuse giving the necessary information. Farmers' refusal to participate increases the errors affecting a survey. Together with a drive towards improved statistical accuracy and efficiency, an alternative system for area estimation was developed that combined and integrated satellite imagery, remote sensing, point frame statistical platforms, GIS and aerial observations from light aircraft.

PICES uses crop field boundaries that are digitized from satellite imagery with a point frame sampling system, to objectively estimate the area planted under grain crops. The PICES process can be summarized as follows:

- Sourcing of satellite imagery;
- Digitizing of crop field boundaries from the satellite imagery (updated annually);
- Point frame design and random selection of sample points;
- Data capturing through aerial observation of sample points; and
- Statistical analysis.

A diagram depicting the advanced sample framework procedure for South African agricultural statistics is available in Annex D.

Sourcing of satellite imagery

The satellite imagery required for the project is made available by the South African government through SANSA (South African National Space Agency), which distributes it to all government departments, including DAFF. Initially, Landsat 5 with a 30 m resolution was used, but in 2006, SANSA signed an agreement with Spot Image (now part of the Airbus Group) to make Spot 5 satellite imagery available annually. Spot 5 satellite imagery at a 2.5 m resolution was used as the base layer for digitizing the field boundary for all nine provinces. The more detailed resolution of Spot-5 imagery compared to Landsat 5 imagery results in a more accurate mapping at a scale of 1:10,000, compared to the 1:100,000 scale available with Landsat 5 imagery.

Initially, in 2006, for Free State, North West, Mpumalanga and Gauteng provinces, the mapping was achieved using LandSat 5 imagery. However, in 2008, for Eastern Cape, Northern Cape, Limpopo and Western Cape, the mapping took place using Spot-5 imagery. The first four provinces that were initially mapped from Landsat 5, were also mapped from Spot 5 in 2009 and 2010, so that all nine provinces had a consistent field boundary layer. Upon completion of the mapping activities, a maintenance program is followed according to which all centre pivot irrigation fields and other changes are updated and modified annually. The field boundary layer for South Africa was updated in 2014, using Spot 5 imagery recorded in 2013. Thus, an up-to-date and recent data set is now available that can be used as an accurate input for stratification and preparation of the annual crop estimate and yield surveys.

Digitizing crop field boundaries from the satellite imagery

The digitizing of crop field boundaries took place in ArcMap, on a scale of 1:10,000 (see Figure 4.9 below). Comprehensive quality control measures were part of the digitizing process, to ensure clean, accurate and high-quality data. Detailed metadata is captured in ArcCatalog as soon as the dataset for a province has been finalized; it is updated whenever changes to the dataset are made. Among the metadata captured are area, category, irrigation and strata. The area (in Ha) is calculated using ArcGIS. The categories refer to Potential Arable field, Horticulture, Old Fields, Pivot Irrigation, Smallholder, and two classes of Non-commercial farming. In the latter category, one class represents small-scale farmers with more defined fields bordering on smallholder farming, while the other class has very small patches of fields that are not easily distinguishable and are thus combined into a single polygon. Irrigation is identified as "Yes" only for centre pivots. The strata identify the field as either:

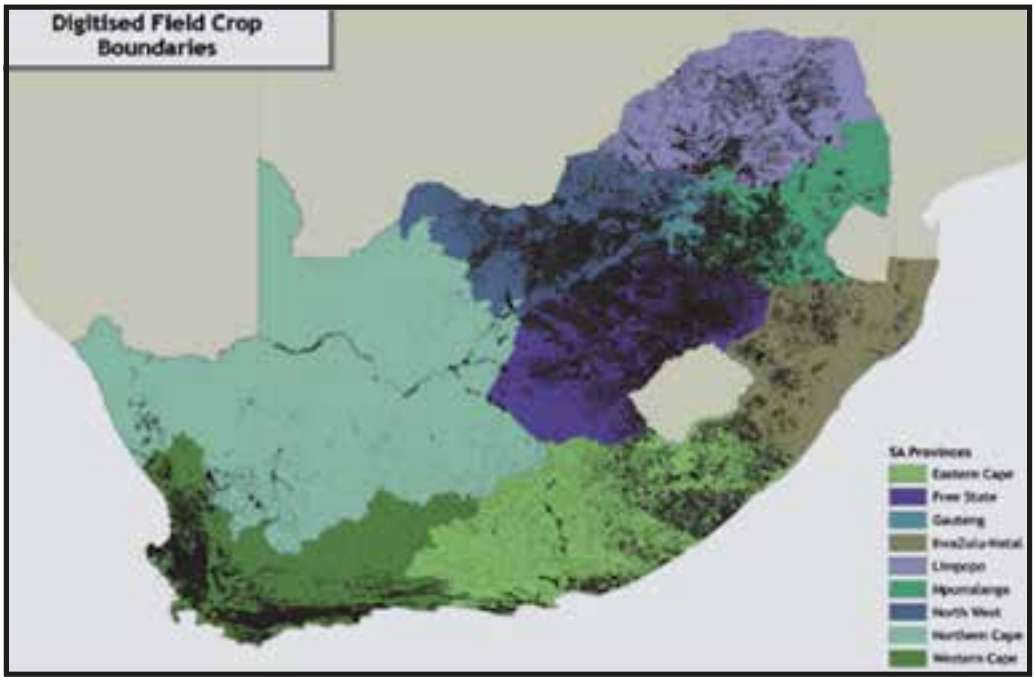
- high-, medium- or low cultivation
- high-, medium- or low cultivation winter crops
- pivot irrigation
- small-scale farming
- old fields or
- small holdings.

Digitization has been completed for all of South Africa's nine provinces, representing a total of approximately 12,965,000 hectares and approximately 800,000 cultivated fields (see Figure 4.10 below). An updating schedule and updating procedures are in place to ensure that the dataset remains up-to-date.

FIGURE 4.9
Digitized crop field boundaries

An example of digitized crop field boundaries and of the SPOT5 satellite imagery used for digitizing the boundaries.

FIGURE 4.10
Coverage of digitized field crop boundaries



The digitalization of field crop boundaries has been completed for all South Africa's nine provinces.

The advantage of using field crop boundaries as the basis for stratification is that it drastically reduces the area that must be covered, as illustrated in Table 4.1 below. This reduction was of 66 percent, 67 percent and 73 percent for the Free State, North West and Mpumalanga provinces respectively.

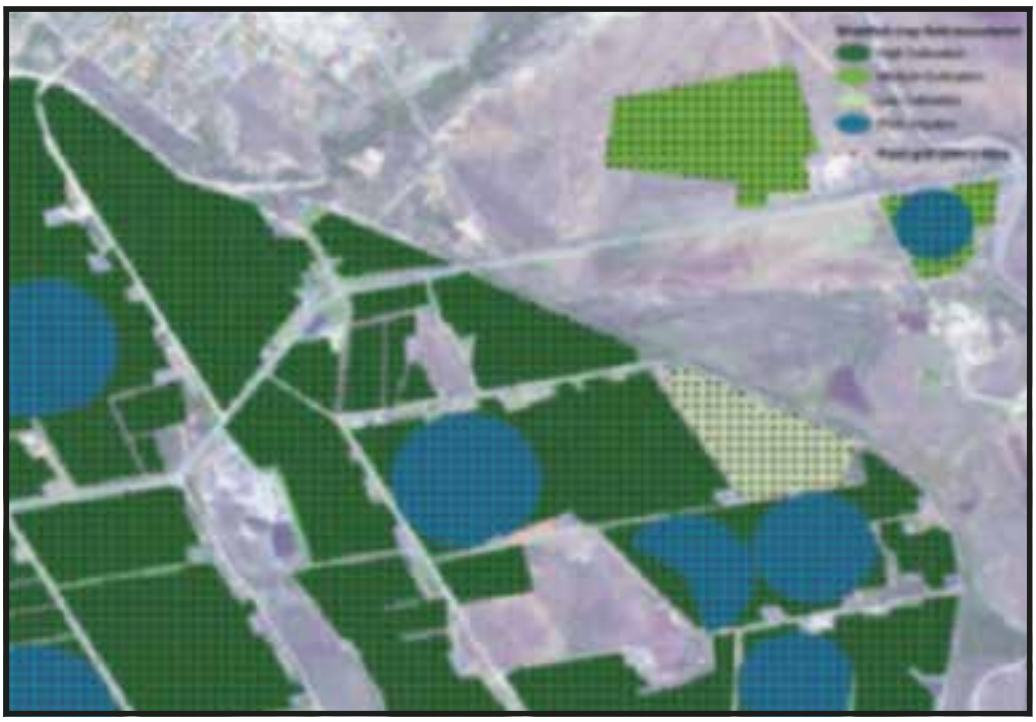
TABLE 4.1
Advantage of using digitized field boundaries to reduce surveyed area.

Advantage of field boundaries: Survey area (ha) reduced				
Province	**Stratification**	**Mapped fields**	**Reduction**	**% Reduction**
Free State	10,794,982	3,712,625	7,082,357	65.61
North West	5,776,803	1,921,927	3,854,876	66.73
Mpumalanga	4,118,568	1,103,706	3,014,862	73.20

Point frame design and random selection of sample points

The next step in the process is to randomly select the sample points (which potentially represent cropped fields) to be surveyed in the field. The starting point for this part of the process is the generation of a point grid of 45 m x 45 m over the total provincial area. The grid points outside the field boundaries are then removed from the total sample population, as these points are highly unlikely to feature any crops (see Figure 4.11 below).

FIGURE 4.11
Random selection of a points sample



A section of the 45 m x 45 m point grid after the removal of grid points outside the crop field boundaries. Crop field boundaries stratification is also shown.

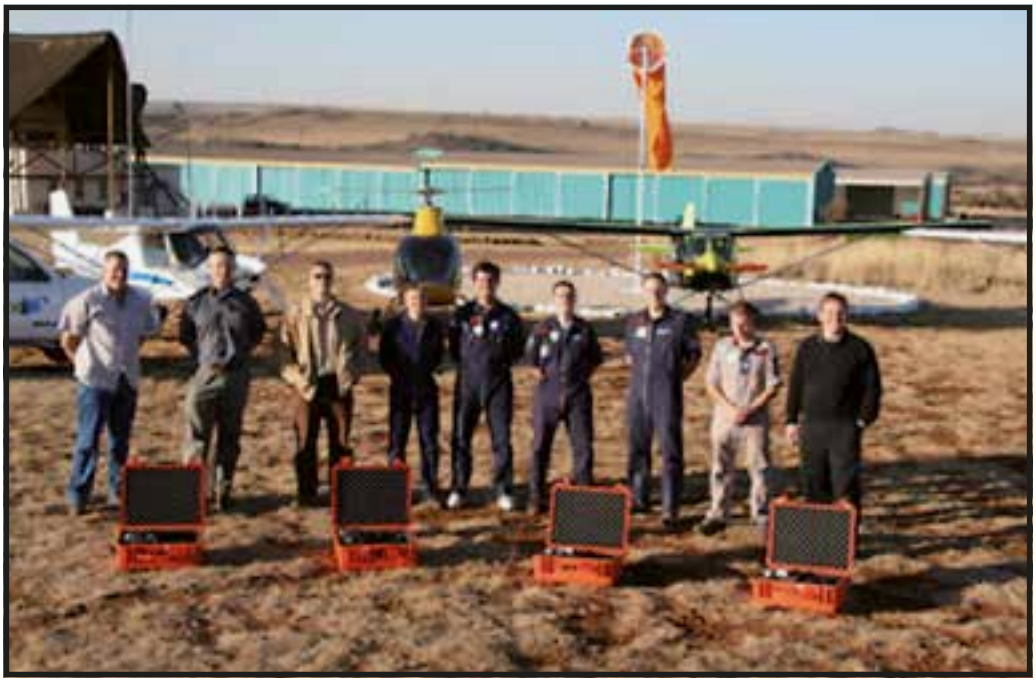
The digitized fields are stratified to indicate the probability of finding a crop. The core strata used are high (greater than 65 percent), medium (30-65 percent) and low cultivation (less than 30 percent), in which the terms "high", "medium" and "low" refer to the densities of fields within any given area, as well as pivot irrigation and small-scale farming. Stratification is performed to increase sampling efficiency. Additional sample points are used in strata in which there is a greater likelihood of finding crops of interest. This will enable the most useful data to be obtained while remaining within the relevant budget constraints, as well as maintaining the CV low.

The grid points are then selected for each stratum and exported to an SQL Server database, where they are sorted systematically from west to east and north to south. This is done to ensure an optimal geographical distribution of the sample points. A random starting point is chosen, and points are selected at regular intervals, according to the number of points required in the specific stratum. The selected points are inserted into a new table in the database and the process is repeated for each stratum. Finally, the SQL Server tables are added in ArcMap and converted to shape-files that containing the sample points for each stratum.

Data captured through an aerial survey of sample points

An aerial survey of sample points is conducted to determine the crop planted on the field represented by each sample point. This aerial survey is conducted by a field observation team which consist of a pilot and an observer flying in a very light aircraft (VLA) (see Figure 4.12 below). The observer is from the agricultural community and very experienced at distinguishing different crops and between dry land and irrigated cultivation. Due to the amount of sample points to be processed during each survey, it is routine for more than one field observation team to be used. This system of capturing field information for crop estimate purposes is unique, and as far as could be established, is not used anywhere else in the world. An area of approximately 12 million ha can be covered in a two-month period using three field observation teams. A further advantage is that this is much more cost-effective than a ground-based system that gathers information from producers, as occurs in the case of the Subjective Area Frame System (in which the locations are visited by means of motor vehicles).

FIGURE 4.12
The VLA used for aerial surveying



Data capturing is performed in ArcPad through a customized user-friendly interface (Figure 4.13a below). A tablet PC, connected to a GPS and located in the aircraft, is used to carry out the data capturing. The field observer captures the crop that was planted at the sample point (see Figure 4.13b), as well as whether the cultivation is dry land or irrigated. Additional information, such as growth problems and areas in which double-cropping takes place, can also be obtained. In addition to the specific data being captured, the observer also takes photographs to provide more information on the conditions in the field during the specific survey. To maximize the usability of the photographs taken, each photograph is automatically

georeferenced. In addition to the observed sampling locations, further information on crop type can be captured by observers as they fly over fields between the sample points. This information is used as training data sets for crop type classification, as described in Section 3.1.3 below.

FIGURE 4.13
Customized interface in ArcPad for data capturing

a) ArcPad user interface to capture field observations. b) Example of fields and locations where crops have been identified through aerial surveying.

Statistical analysis

The field data is captured and stored in GIS format. This data is uploaded onto a central server on a daily basis and is then imported into an automated SQL Server database. Similarly to the Subjective Area Frame System, the data is expanded (using expansion statistics) to all the fields in the strata to obtain a statistically derived estimate of the area planted for each crop per province. The results are then presented to the CEC meeting.

3.1.2. The agricultural census and baseline mapping

During 2007, the Maize Trust funded a project undertaken by the NCSC to conduct a census of all fields within the Gauteng Province. The aim of the project was to:

- provide an ultimate benchmark for the area planted under maize in Gauteng Province by conducting a PICES-based census;
- compare all possible information provided to that of the census with regards to the area planted under maize; and
- enable the CEC to use the results as a possible weighting tool for information providers of area estimates.

It was found that the census conducted accurately reflected the reality on the ground, and that the results obtained should be considered accurate. The PICES sample method of determining area planted, as well as any other area estimate from other methods, could be evaluated against this benchmark. The PICES sample result for area planted was within 1.9 percent of the census result for the maize area planted.

The stakeholders considered the results and suggested that the census results of the area planted in the Gauteng Province should be used as a benchmark for all other inputs into the CEC. It confirmed that the PICES methodology of determining crop area can be regarded as accurate and reliable.

Based on the success of the Gauteng census, in 2009 the Gauteng Department of Agriculture and Rural Development (GDARD) contracted an Agricultural Census and Baseline Mapping project for the province. This was followed by the Limpopo Department of Agriculture (LDA) in 2011 and by the Western Cape Department of Agriculture in 2013.

3.1.3. Crop field classification

As a verification of the PICES survey, the NCSC developed a method of crop classification using remote sensing. Although this only becomes available after the relevant season, this data can verify the area estimates and provide a more spatial representation of land use change from season to season. The information gathered during the PICES was used as training sets for satellite imagery classification procedures, to generate a crop type for each individual field. During the growing season, both Landsat 5 and Spot 2 and 4 images were recorded and used to perform a crop type classification. From examination of the classified satellite imagery, the crop type was assigned to individual field polygons to provide a complete set of classified fields for the selected province.

In detail, the process is the following. The field boundary polygons digitized from SPOT5 imagery as described in Section 3.1.1 above were used as basis for the crop type classification. Images within the growing season were obtained and included Landsat 5 as well as Spot imagery, but due to cloud cover a number of images could not be used. Suitable images with the least cloud cover were selected for the months of February and March, which coincide with the maximum vegetative development of the summer grain crops. All clouds were mapped for each individual image, and the fields intersecting with cloud polygons were removed before further processing. Field boundaries were used as masks, to retain only the spectral information within the fields; this was done to enhance the image histogram for crop type discrimination.

Information on crop types captured during the aerial survey was used as input to the image training procedure (see Figure 4.14 below). The additional information on crop type captured between selected points was used as training for the signature files, while the sample points with crop type information was retained for accuracy assessment (Table 4.2 below). According to the ratio of crop types generated from the aerial field surveys (based on the four major grain-producing provinces: North West, Gauteng, Mpumalanga and Free State), fields planted with maize covered 80 percent of the summer grain fields, while sunflower seed covered only ten percent and soybeans five percent, with other crops covering less than two percent. This ratio of very few points for crops with low representation led to an absence of field verification samples for certain images. To overcome this problem, satellite images recorded on the same day were re-mosaicked together, which resulted in the restoration of satellite paths and image strips and thus enabled field verification across a larger area; this improved the chances of all crops being represented. This approach improved the possibility

of generating signature classes for all crops on all images, although in certain individual scenes this was not always possible.

FIGURE 4.14
Demonstration of crop type classification by aerial surveying fields in the Free State province

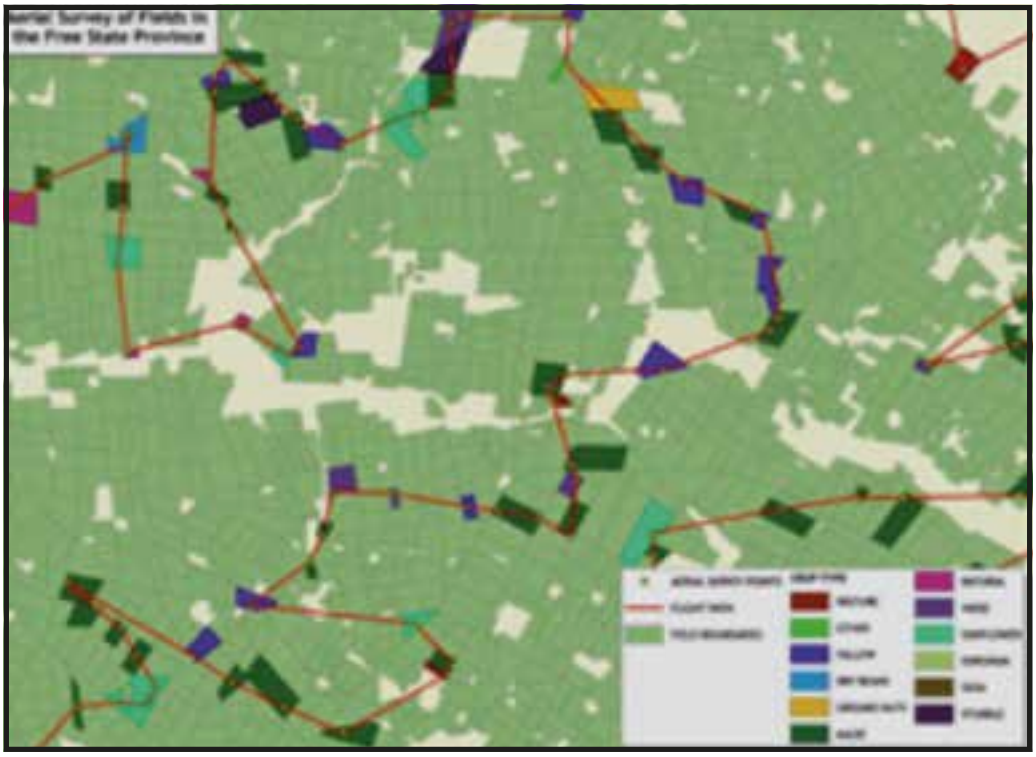


TABLE 4.2
Number of points captured for the PICES summer crop area estimate and the additional number of crops captured to be used as training data sets for crop type classification

PICES Crop Type Points/Province: Summer 2006			
Province	**Selected**	**Additional**	**Total**
Mpumalanga	1048	1852	2900
Freestate	1582	2618	4200
NorthWest	1288	1812	3100
Gauteng	319	230	549
Total	**4237**	**6512**	**10749**

Signature files were generated for each field's masked image, considering the crop phenology stages for each crop type (Figure 4.16 below). Crop type development takes into consideration seasons, summer and winter temperatures, as well as summer and winter rainfall. Other markers of crop type are vegetative growth stage and cultivation practice. Crop

fields are buffered by a 60-m inward border to exclude pixels on the edges of fields or that are not "pure" but feature, for example, half crop and half road reflectance.

FIGURE 4.15
Crop type classification development calendar for summer crops

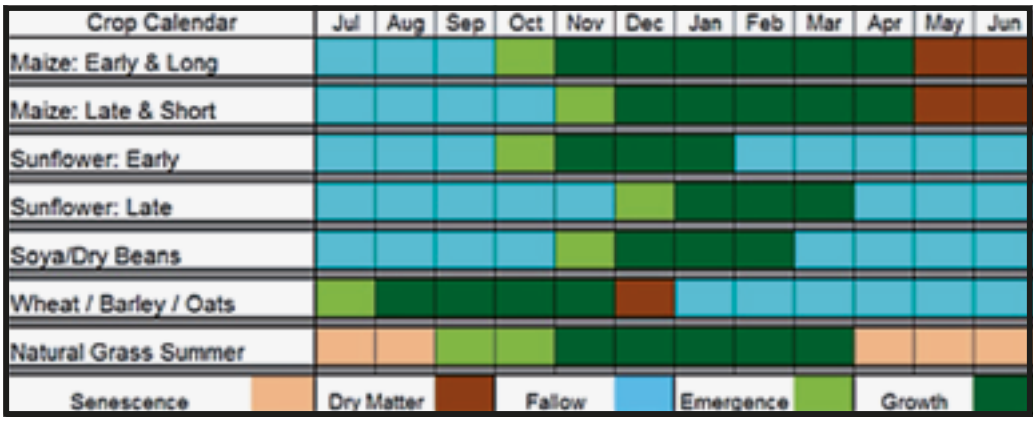
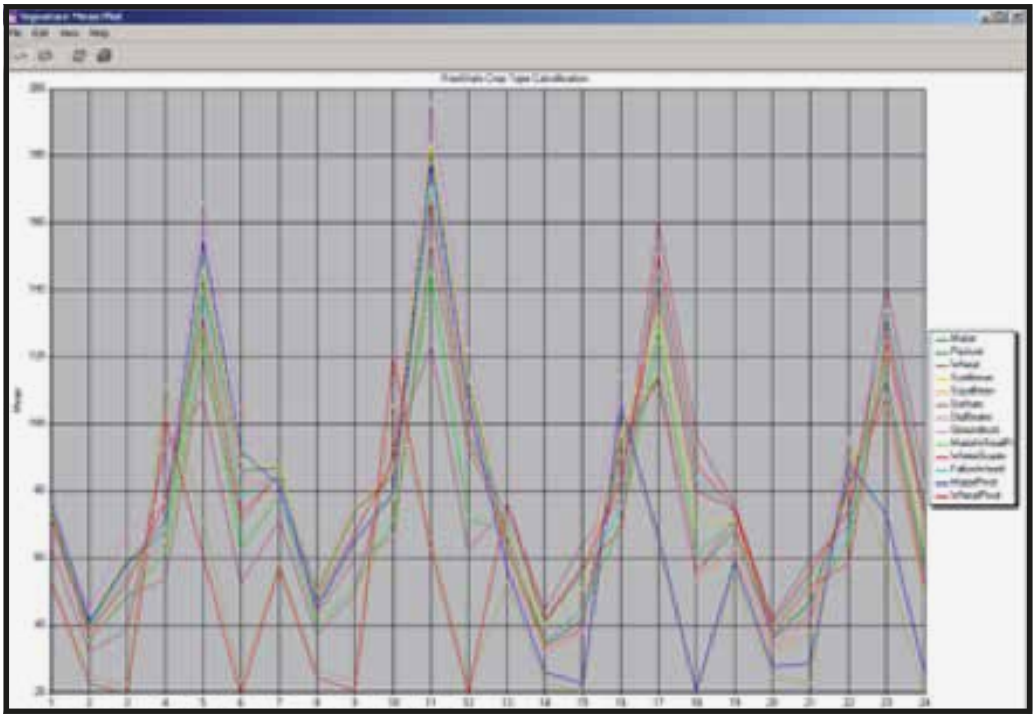


FIGURE 4.16
Free State crop type classification



Signature sets were evaluated separately for each image using a Jefferson-Matusita analysis, and each signature class in a set was refined to reduce overlap between classes. Before classification, the different bands in each image were also evaluated to determine the best combination to discriminate between different crop types. It was found that generally, the red

band along with the infra-red bands provided the best separation. The images were classified using the ERDAS supervised classification approach and selecting the maximum likelihood, combined with the parallel-piped functions (Figure 4.16 above). Crops such as soybeans and sunflower seed have typically shorter crop phenology cycles compared to maize. Therefore, it should have been possible to discriminate on this basis. However, in practice, this did not occur. Farmers generally stagger planting dates for all crops from October until December to spread the risk of erratic rainfall across the season, which makes it impossible to fix the crop calendar for specific crops according to planting dates or times of harvest.

After the supervised classification procedure, a zonal majority function was used to assign a crop type to each field boundary polygon based on the raster classification. This step enabled generation of a file with a crop type for each field during a specific season for the entire province, providing a basis for various queries and analyses.

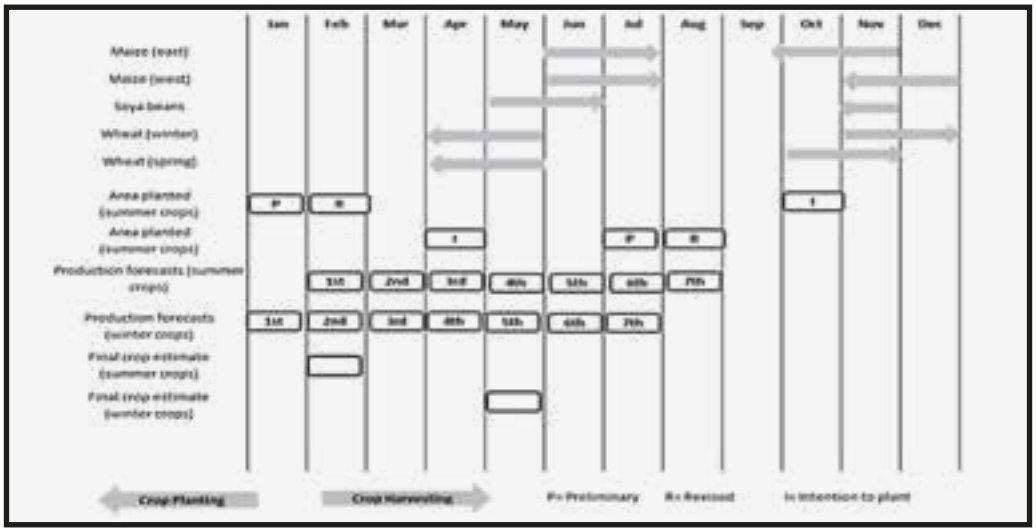
Through integrating and combining technologies, it was possible to calculate statistical area estimates for each province through aerial surveys while also generating a map that showed the spatial distribution of crop type patterns. It is now possible to extract information at sub-provincial level, such as agro-climatic zones or district level, or any polygon boundary of importance. This provides decision makers with possibilities for spatial analysis that were not previously available.

This method was used for the four major summer grain-producing provinces (North West, Mpumalanga, Free State and Gauteng) in 2006 based on the 2005/06 production season. The methodology covered 280,000 fields, representing 6.5 million hectares across all four provinces. These provinces represent approximately 90 percent of the total area in South Africa under summer grain production. Due to cost constraints, this procedure was only continued for the Free State for the 2007, 2008, 2009 and 2010 seasons. Because of uncertainty on the maize area under production in the North West province, in 2010 it was decided to channel the funds towards crop classification in this province rather than in the Free State. Crop classification is available for the North West Province for 2011, 2012, and 2013.

3.2. Release calendars: punctuality and timeliness

In accordance with the terms of the contract, the NCSC undertakes the area estimate (PICES) for summer crops during January and February for Gauteng, Free State, Mpumalanga, North West, KwaZulu-Natal and Limpopo and presents the estimate figures to the CEC during the February meeting. For the winter crops, the survey is undertaken in August for the Western Cape and in September for the Free State; these are presented to the CEC during the August and September meetings. Table 4.3 below provides a complete description of the release frequency of production forecasts and estimates and acreage estimates in South Africa, together with the planting and harvesting calendar of the main crops.

TABLE 4.3
Crop calendar and release frequency of crop forecasts and estimates



3.3. Human, financial and technical infrastructure

Area estimates are the main component of the NCSC's contract with DAFF. All data collected is under the DAFF's custodianship and is usually not publicly released until after the season of collection, i.e. once the harvests are complete.

5

Crop Yield Forecasting in the United States of America

Michele Bernardi[1]

1. Crop yield forecast data made available for the USA

1.1. Brief description

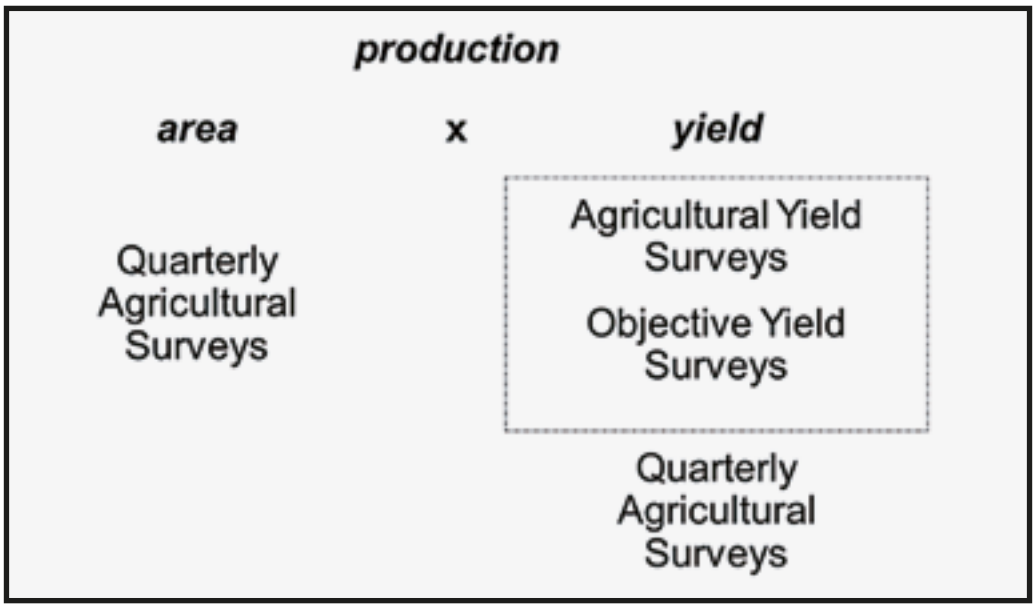
In the USA, domestic supply is a key factor in the marketing of any commodity, and affects the industry's business decisions. Considering the importance of agricultural commodities, crop production forecasts and estimates are considered to be extremely sensitive data, and the greatest accuracy must be applied in computing and handling them. Crop yield forecasting is performed at county level through a statistical model that use as input data the results of sophisticated field surveys. The output of the model is then aggregated at state and national levels. Remotely sensed imagery provides a great deal of support in computing crop acreage estimates. Compared to other countries, the nationwide official crop yield forecasting system is not based on a combination of indicators provided by crop-soil-weather simulation models and remote sensing. All activities regarding production forecasts and estimates of agricultural commodities are centrally managed by the US Department of Agriculture (USDA[2]). Each month, the USDA releases crop supply and demand estimates for the United States and for the world, with the support of several agencies within the USDA entrusted with the preparation of crop statistics. At national level, the USDA enjoys the technical support of

[1] Independent Consultant.
[2] USDA: http://www.usda.gov/wps/portal/usda/usdahome

the National Agricultural Statistics Service (NASS[3]), which forecasts US crop production on the basis of data collected from farm operations and field observations; the NASS uses a statistical model to forecast crop yield and production.

The USDA uses various methods to obtain crop yield estimates, such as actual data from growers (area/trees planted/harvested, quantities harvested/sold/stored), growers' expectations (areas expected to be planted/harvested, expected yields), objective counts and measurements (plant/fruit counts & measurements), expert opinions (crop progress, growing conditions), and remote sensing. Expected corn and soybean yields are obtained on a monthly basis from August through November, from two different types of yield surveys; final measurements are made in December (see Figure 5.1 below).

FIGURE 5.1
Synthetic flowchart of crop acreage, yield and production estimates



Source: Holland 2011

The USDA computes crop production estimates by combining data on area, obtained through Quarterly Agricultural Surveys, and data on yield, obtained through Agricultural Yield Surveys and Objective Yield Surveys.

[3] USDA-NASS: http://www.nass.usda.gov/

1.2. Inventory of forecasts available, by source

1.2.1. Official national sources

The USDA coordinates two types of crop forecast surveys: a grower-reported survey and an objective measurement survey. The former survey, the Agricultural Yield Survey (AYS), provides farmer-reported survey data of expected crop yields, which are used as input to forecast and estimate crop production levels throughout the growing season; it is conducted in all states except Alaska and Hawaii. The latter survey, known as the Objective Yield Survey (OYS), covers wheat, corn, soybeans, cotton, and potatoes.

The NASS works with crop analysts to provide useful imagery and data products on a timely basis. The primary purpose of this visualization is to provide near real-time capability, using satellite data to monitor crop growth and progress in the USA's major production areas. The satellite data provides an independent source of information that supplements the survey data collected by the enumerators. Crop analysts use the satellite imagery, integrated with a GIS, to support their assessment of the current crop condition and vegetation index. The NASS uses its GIS capability to combine various layers of information and to overlay image data with state and county boundaries, frost isoline data, and crop information. This visualization focuses on the integration of GIS map products, including AVHRR image data, the crop progress of specific stages of crop development, crop conditions, frost isolines and survey data. The Intranet version allows for the visualization of crop progress and condition data at the county level, and of farmer-reported survey data indications, which cannot be released. The NASS uses the data collected to compile monthly reports on farmers' planting intentions, estimates of crop acreage planted and expected to be harvested, and forecasts of crop yield and production during the growing season. After the crop harvest, the NASS estimates the harvested crop acreage, crop yields, and crop production using the abovementioned surveys. The final crop estimate is determined on the basis of survey data indications, administrative data and all other known information, to produce the official estimates. The GIS and remotely sensed data are a supplemental tool for the visualization of a growing season.

1.2.2. Other non-official national sources

Other sources also provide real-time information on crop yield at state level. For example, the AgroClimate[4] is an innovative web resource for the Southeastern USA; designed for decision-support and learning, it provides interactive tools and climate information to improve crop management decisions and reduce production risks associated with climate variability, climate change, and extreme weather events. Users can monitor variables of interest, such as growing degree days, chill hours, freeze risks, disease risks for selected crops, and current and projected drought conditions. Users can also learn about the impact of climate cycles that affect the Southeastern USA, such as the El Niño Southern Oscillation (ENSO). AgroClimate uses process-based models together with historic, current, and forecasted climate data, to enable decision makers to compare changes in the probable outcomes under different climate conditions.

[4] AgroClimate: http://agroclimate.org/tools/County-Yield-Statistics/

1.2.3. Other regional and global sources

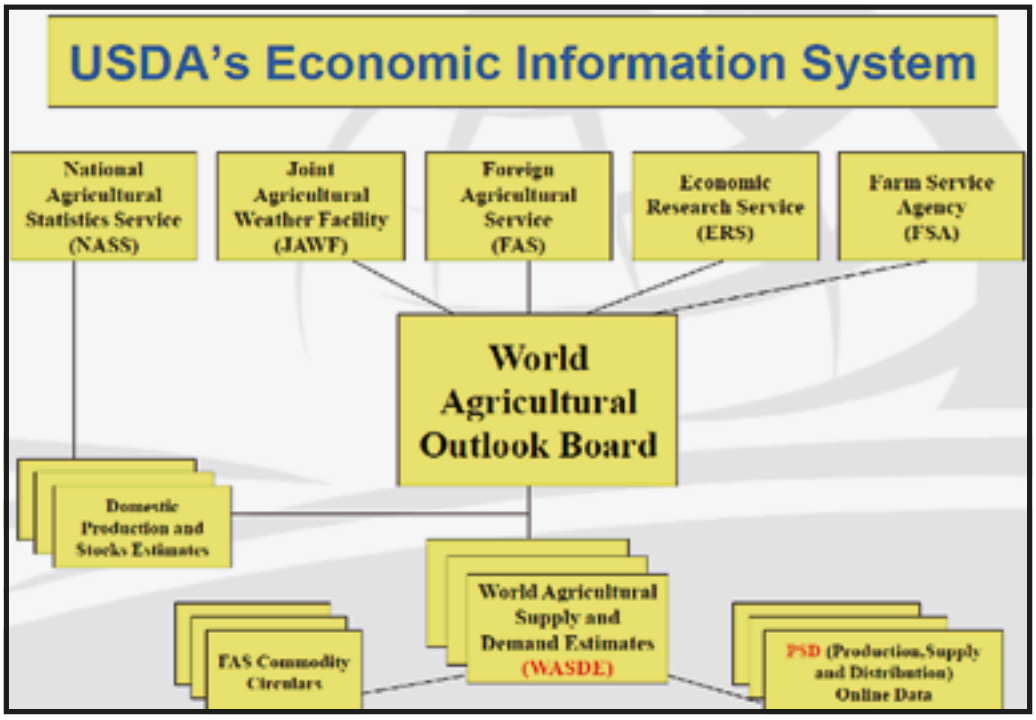
Within the USDA, the economic information system performs a great role, especially with regard to worldwide crop production prospects. The system includes the Joint Agricultural Weather Facility (JAWF[5]), which was created in 1978 as a collaborative effort between the NOAA[6] (National Oceanic and Atmospheric Administration) and the USDA to keep crop growers, exporters, and USDA commodity analysts informed of worldwide weather developments and their effects on crops and livestock (see Figure 5.2 below). NOAA's Climate Prediction Center (CPC[7]) provides climate and weather data to the USDA's agricultural meteorologists, and creates special products for major crop areas worldwide to assist the USDA in its crop assessment activities. The USDA's agricultural meteorologists use this information, together with agronomic data, to ascertain the weather's impact on agricultural production both nationally and internationally. The most important reports published by JAWF are:

- the US Agricultural Weather Highlights;
- the Weekly Weather and Crop Bulletin;
- the Major World Crop Areas and Climate Profiles; and
- the World Agricultural Weather Highlights.

Within the USDA, the Foreign Agricultural Service (FAS[8]) obtains information on foreign production, use and trade through a network of 75 agricultural attachés, who cover 110 countries around the world (see Figure B5.1, Annex B5.1). In FAS, this information is assembled and reviewed by commodity and trade analysts of the Production Estimates and Crop Assessment Division (PECAD). FAS monitors world agricultural production and the world supply and demand for agricultural products, to provide baseline market information and information that can the US to issue domestic early warnings, if necessary. FAS analyses rely upon a combination of meteorological data, field reports and satellite observations at moderate and high spatial resolutions to assist crop and growth stage identification, and yield analysis. These data are used to confirm or deny unsubstantiated information on forecast crop yields, and to identify unreported events that are likely to impact crop yields. For these purposes, FAS has developed the Crop Explorer[9], a GIS-based decision support system (see Figures B5.2 and B5.2A4, Annex B5.1).

[5] JAWF: http://www.usda.gov/oce/weather/
[6] NOAA: http://www.noaa.gov/
[7] NOAA-CPC: http://www.cpc.ncep.noaa.gov/
[8] USDA-FAS: http://www.fas.usda.gov/
[9] USDA-FAS-PECAD: Crop Explorer: http://www.pecad.fas.usda.gov/cropexplorer/Default.aspx

FIGURE 5.2
The USDA economic information system



Source: Reynolds 2013.

The USDA's Economic Information System consists of the NASS, JAWF, the FAS, the ERS and the FSA. The latter four services are part of the World Agricultural Outlook Board, which is the USDA's focal point for commodity outlooks for US and world agriculture.

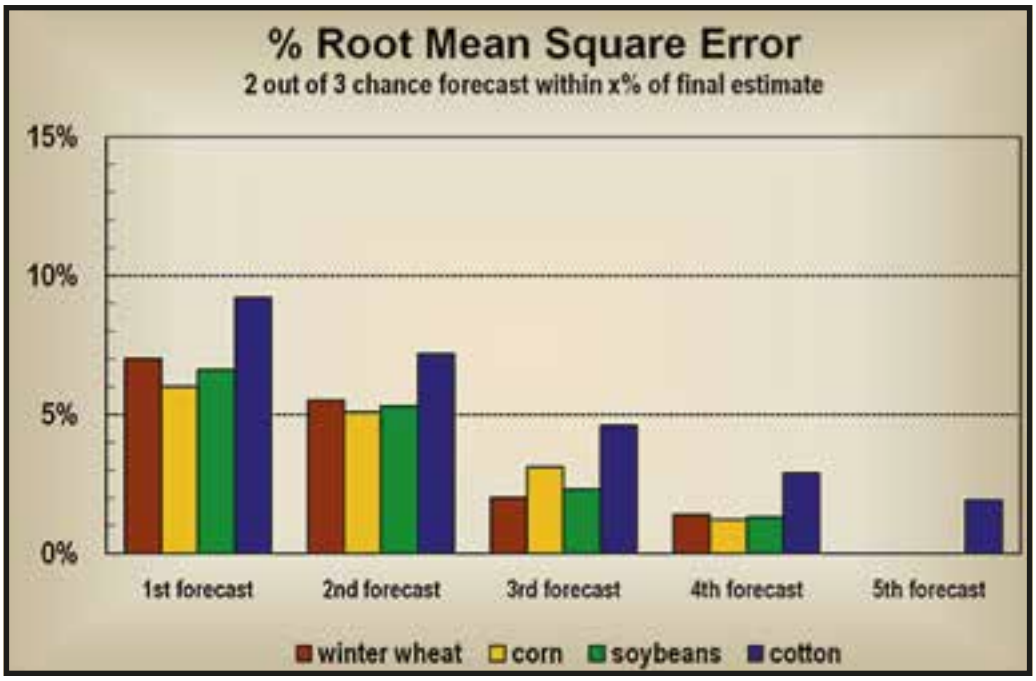
1.3. Release calendars: punctuality and timeliness

Forecasts for each crop season begin with a winter wheat report issued in early January, followed by a report issued in March that provides initial information on the farmers' intended planting plans. In late June, this is followed by a report of the acreage that was actually planted. Monthly yield and production forecasts begin in May for winter wheat, in July for spring wheat and other small grains, and in August for other spring-planted crops, concluding with estimates of the actual production at the end of the harvesting season. The NASS also conducts quarterly surveys of the grains and soybeans stored on and off farms. During mid-season (August to November), the NASS hires approximately 350 enumerators for each top-producing state (for a total of about 5,000 enumerators), who collect the ground samples used for the NASS' monthly objective yield surveys. Each NASS state office then submits their monthly state crop yield estimates (with sample ground data collected by the enumerators) to the NASS headquarters. The NASS headquarters then compiles all the state data and obtains the official USDA monthly yield estimates for the country (from August to November). The monthly crop production bulletin is released every 10th day of the month at 12:00 noon.

1.4. How do these different forecasts compare? Purpose, coverage, scale and harmonization issues, and accuracy

At national level, there is only the USDA-NASS' official crop yield forecast system. The statistical data are adjusted monthly, on the basis of filed surveys, weather data and remote sensing. The forecasts are highly reliable, and forecast errors decrease as the harvest time approaches (see Figure 5.3 below). It is unclear whether the statistical crop yield forecasts at state or county level are supported by the outputs of the crop-soil-weather simulation models provided by local institutions and universities.

FIGURE 5.3
Reliability of US Crop Production Forecasts



Source: Holland 2011.

The US crop production forecasts are very reliable: the RMSE always remains below 0.1, and decreases further as harvest time approaches.

2. The USA's official national sources: methodology and practices

2.1. Description of the general yield forecasting methodology

Crop production forecasts and estimates have two components: the number of hectares to be harvested and the yield per hectare. A full program of forecasts and estimates includes determinations of the areas planted at the beginning of the growing season, the estimates

of areas to be harvested for grain, the yield forecasts during the season, and the final area and yield after harvest (USDA-NASS 2012). For example, estimates for the planted acreage of corn and soybean are computed using data obtained from a survey of farmers conducted during the first two weeks of June. The expected corn and soybean yields are obtained on a monthly basis, August through November, from two different types of yield surveys. The area to be harvested for grain is measured in June and is monitored throughout the season. The final acreage and yield are measured in December. The farm operators provide data for the small grain crops (winter wheat, durum wheat, other spring wheat, barley, oats), row crops (corn, cotton, dry edible beans, peanuts, rice, soybeans, sorghum, sugarcane), tobacco (burley, air cured, and dark fired), and hay (alfalfa and other hay) produced on the operation. Data on hay stocks are also collected. Data on the area planted, the area to be harvested, and the expected yield per hectare are collected on the first month from each operator for the crop of interest. In the following months, the same sample of operators is contacted for updated data on the expected yield per hectare. Updating the reported information from the same sample of operators every month enables the change resulting from the growing conditions to be monitored.

The two types of crop yield surveys, the AYS and the OYS, are described in further detail below.

2.2. Relevant practices for data collection

2.2.1. The Agricultural Yield Survey

The AYS is the survey of growers and covers all major field crops included in the NASS's estimating program. The growers in the sample are asked to provide, on a monthly basis, their assessments of the yield prospects for their crops. The data collected from AYSs also reflect the seasonal growing conditions and weather events up to the first of the month. Also, the AYS datasets have been accumulated over time, and form an integral part of yield forecasting. In the context of AYSs, the impact of the growing conditions and weather events on the yield of the year under study may be derived from the respondents' collective perceptions, judgments, and experience gathered over the given period of time.

2.2.1.1. The sampling frame and sampling design

The AYS samples are drawn from respondents in list strata, during the March (MAS) and June (JAS) Crops/Stocks Surveys. A small grains (SG) sample to be used May through August is drawn from the MAS, from respondents who reported having a small grain crop of interest. A row crops (RC) sample to be used August through November is drawn from the JAS, from respondents who reported having a row crop of interest. Operations in the largest (preselected) list strata are excluded from the AYS sampling.

The AYS uses a Multivariate Probability Proportional to size (MPPS) sample design, using list frame control data to determine the probability that a unit will be selected. In a more basic PPS sample design, the units are selected by size, depending on the proportion of the

commodity of interest within the operation compared to that within other operations of the list frame. The MPPS sample design is similar to a traditional PPS sample design, but several commodities or control items are used to determine a unit's probability of selection. In MPPS sample design, a sample size is targeted for each commodity of interest for which frame data is available. The resulting probability of a unit's selection is determined by the commodity that constitutes the largest proportion of the total, and the sample size for that commodity.

In certain months (for example, August in most states) the AYS sample may include operations from both samples; therefore, a composite weighting methodology was developed. This approach enables maximum use of the information obtained from AYS responses. Under MPPS sample design, stratification is not used as an underlying component. However, the strata are used in computing nonresponse adjustment weights (USDA-NASS 2012).

2.2.1.2. Data collection

The monthly Agricultural Yield runs from May through November.

- Small grains data are collected from May through August.
- Row crop data are collected from August through November.
- Hay yield data are collected in August and October, with hay stocks (data?) collected in May.
- Tobacco data are collected from May through November.

The reference date for each AYS is the first day of each month. In practice, the data collection period begins on the 25th of the previous month and ends on approximately the 5th day of the survey month. The survey instruments are prepared in paper and electronic formats. Most data are collected in electronic form, using Computer-Assisted Telephone Interviewing (CATI) techniques. Several states collect some data by mail; however, the short data collection period limits this activity. For a small number of samples, face-to-face interviews are conducted, due to special reporting arrangements or other considerations. Electronic data reporting (EDR) via the Internet began with the 2006 crop year.

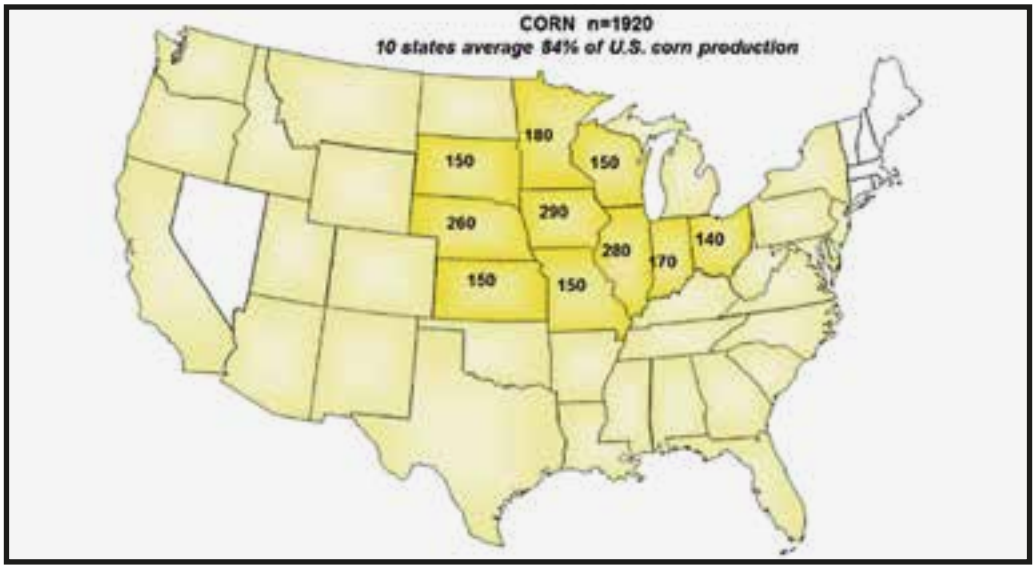
The sample sizes range from 5,500 (June) to 27,000 (August). The states are expected to achieve a minimum response rate of 80 percent. To meet this minimum level, the states are expected to conduct a follow-up of the mail and telephone operations to which there has been no response. The states must also monitor the responses by crop, to determine the amount of follow-up required to achieve 50 usable reports for the major crops (USDA-NASS 2012).

2.2.2. The Objective Yield Survey

The objective measurement surveys, known as the OYSs, cover wheat, corn, soybeans, cotton, and potatoes. The OYSs consist of a sample of fields in which counts and measurements are carried out with respect to plants in random plots laid out in each field (see Figure 5.4 below). The data collected from the yield surveys reflect seasonal growing conditions and weather events, as of the first day of the month. The resulting historical accumulation of monthly OY data, collected under a variety of growing conditions, is an invaluable forecasting asset. The implicit relationship between OY data and seasonal growing conditions is also explicitly

evaluated, using temperature and precipitation data relative to "normal". Departures from the normal benchmark are evaluated not only for the current year, but also for the range of historic years under consideration. An assumption that "normal" conditions exist is held for the remainder of the growing season. Corn Objective Yield (COY) surveys are very costly, and are conducted only in the top producing states, i.e. Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin. On average, over the last three years, these ten states have produced over 83 percent of US corn production.

FIGURE 5.4
Objective Yield Sample Sizes



Source: Holland 2011.

Sample size for the COY surveys: the 10 states surveyed (Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin) cover, on average, 84 percent of US corn production.

2.2.2.1. The sampling frame and the sampling design

All OY samples are drawn from an area frame parent survey (March or June Crops/Stocks Survey); the only exceptions are the potato and winter wheat OYSs, which use list frames. The area frame is defined as the US' entire land mass, and ensures complete coverage of the US farm population. The most important statistical result of the area frame construction is that for OY studies, any crop acre can be assigned a known inclusion probability.

Area data for June are collected and recorded at the field level, multiplied by the inverse of the sampling fraction, and then added, to obtain State totals. OY fields are systematically selected from the acres of the crop under study. In other words, OY samples are selected according to a PPS method, which makes them self-weighting samples. The detail of the recorded area data allows for sample selection down to the exact field. Fields with large acreages or expansion factors may be selected for more than one sample. Separate plots are laid out for each sample within a field for up to four samples.

Potato and winter wheat acres are collected at farm level on the Crops/Stocks questionnaire, multiplied by the inverse of the sampling fraction adjusted for non-response, and added in the summary program. The farms are selected in accordance with a PPS method. The fields are selected within farms by means of a PPS method, by enumerators, during interviews with the farm operators; therefore, this too is a self-weighting sample. Using this design, farms, and fields within farms, may be selected more than once (USDA-NASS 2012).

2.2.2.2. Data collection

A full OYS collects data at different times during the growing season. During the initial OYS, the operator is asked to verify the acreage reported in the parent survey. This is accomplished on a field-by-field basis. Any changes may be due to recording or reporting errors in the parent survey, failure to fulfil planting intentions, or switching to other uses. Other data concerning the crop, e.g. the planting date and the use of genetically modified seeds, are collected during this stage. The final question requests permission to enter the sample field and to perform counts and measurements throughout the growing season.

The initial visit to the sampled acre involves a precise selection of the plants from which fruit counts and measurements, and maturity determinations, will be made for the remainder of the growing season. In terms of crops, the samples have identical dimensions. Applying additional precautions during sample layouts ensures that the exact same plants are revisited in subsequent months. Plant counts, and a variety of plant characteristics counts, are collected from these samples and used to forecast the gross yield and the components of yield, such as the number of fruit and the weight per fruit. During the final visit, all harvestable yield is obtained, which will determine the final gross yield. The counts and measurements from all visits are added to a five-year historical database, which is used to forecast the gross yields of the following season.

After the sample field has been harvested, the post-harvest gleaning data are collected. All unharvested fruit and loose grains are gleaned from specially prepared plots, which are separate from the original sample plot. The calculations from these plots are deducted from the gross yield, to reach a net yield number. Before the gleaning data become available, a five-year average harvest loss is assumed when calculating net yield (USDA-NASS 2012).

2.2.3. The input from meteorology

Long-range weather forecasts are not used in any forecast models; after the first day of the month, growing conditions and weather events are evaluated in the following month's forecast. A significant change in conditions or a weather event between the survey period and the report release date, such as a freeze, a serious heat wave, beneficial rains, etc., will not alter the forecasted values, which were based on the conditions existing on the first day of the month. The NASS' policy requires forecasts to be based on the conditions of the first day of the month, the period that corresponds to the data collected in the OYS and AYS (USDA-NASS 2012).

2.2.4. The use of GIS tools

The main tools used to forecast crop yield are scientifically selected sample surveys from a very long list of farm operators (the list frame) and from the parcels of land of the entire country (the area frame). However, the NASS and crop specialists use GIS[10] tools and remotely sensed data to obtain a near real-time capability for a visual monitoring of crop growth and progress in the major production areas, on a weekly basis. Through the GIS capability, various layers of information (i.e. NDVI images, the crop progress of the specific stages of crop development, the crop conditions, frost isolines, survey data) are combined and visualized at state and county level (Wade and Hanuschak 1999).

2.2.5. Inputs from remote sensing

In recent years, the USDA has developed two main geospatial web service-based platforms to integrate field survey data and remotely sensed imagery, for the purpose of visualizing agricultural data at county level. The USDA-NASS constructs a new area-based sampling frame for approximately two states each year. The remote-sensing acreage estimation project analyses satellite data for the major corn- and soybean-producing states, to produce independent crop acreage estimates at state and county levels and a crop-specific categorization called the Cropland Data Layer (CDL). To date, the CDL program has produced crop-specific land cover products in over 29 states, with an annual repeat coverage for 13 agriculturally intensive states. The USDA-NASS' Remote Sensing Section (RSS) developed the CropScape[11] platform to produce NASS annual CDLs for the US; the platform is derived from imagery from the NASA-Landsat-8[12] and DMC/Deimos[13] satellites (see Figures B5.2 and B5.2a, Annex B5.1). The CDL allows: (i) to combine remote sensing imagery and NASS survey data to produce supplemental acreage estimates for the state's major commodities; (ii) to produce a crop-specific digital land cover data layer for distribution in industry-standard "GIS" format; (iii) to produce a census by satellite with measurable error and unbiased estimators. The NASS' CDL is officially released approximately two months after harvest (around January of each year).

The NASS has also formed a partnership with the USDA's Agricultural Research Service, to use satellite data as inputs for setting early season small-area yield estimates in several midwestern states. The new platform will use both the crop area CDL (30-m resolution) and MODIS-NDVI[14] data (250-m resolution), for an annual "crop yield" product that shows the relative yields for corn and soybeans within each field. These NASS remote sensing-derived products for crop area and crop yield are released after the harvest, while the monthly NASS crop yield forecasts made during the mid-season (from August to November) are essentially founded on ground-based surveys for each state (or for the top-producing states for the commodity under study).

[10] GIS: Geographic Information System
[11] USDA-NASS-RSS CropScape: http://nassgeodata.gmu.edu/CropScape/
[12] NASA-Landsat-8 satellite: http://landsat.gsfc.nasa.gov/?page_id=4071
[13] DMC-Deimos satellite: http://www.geo-airbusds.com/en/84-deimos-1-optical-satellite-imagery
[14] NASA-MODIS-Land: http://modis-land.gsfc.nasa.gov/vi.html

During the growing season, the NASS also produces vegetation condition products on the basis of the NDVI, from the NOAA-AVHRR sensor, which provides the Department of Agriculture's policymakers with an independent view of growing conditions across the country. To this end, the second platform is VegScape[15] (see Figure B5.4, Annex B5.1), and enables: (i) the improvement of the objectivity, robustness, quantification, and defensibility of the nationwide crop condition-monitoring programme; (ii) free online satellite-based assessment and monitoring of US crop conditions; (iii) the provision of tools for data exploration and visualization; (iv) the free dissemination of geospatial vegetation conditions at daily, weekly, and biweekly time intervals.

2.2.6. The main constraints

The NASS program uses a statistical model to forecast crop yield and production[16]. State or regional estimates are obtained by first aggregating the input, and then using a statistical model. The advantages of using statistical models is that the calculations are simple to make, less time is required to run the model and the data requirements are limited. However, they are limited in terms of the information that they can provide beyond the range of values for which the model is parameterized. Also, while still being statistically correct, the output of these models may not have any agronomic significance. In addition, the models do not take into consideration the soil-plant-atmosphere continuum, which is important when dealing with regions having different soil types. For example, the response of a crop to a given amount of rainfall on sandy soil is different from that which the crop would display on a clay soil. The timing of the water stress occurring during the growing season is also important, and often ignored. For example, a heat stress that happens at flowering will reduce yield more than a heat stress occurring during the vegetative phase. This is important for the correct forecasting of yield, and for providing farmers with important agronomic advice (e.g. the timing and amount of fertilizer, time of sowing, irrigation, and so on). There are efforts to include more meaning into the statistical models, to avoid some of the problems described above. For example, the inclusion of crop evapotranspiration or the initial soil moisture content (obtained through microwave sensing) as parameters of the model, may improve predictability, but leaves agronomic questions unanswered (Basso et al. 2013)

2.3. Relevant practices for data sharing and analysis, harmonization, and integration

The dissemination of reports follows a regular and precise schedule:

- Monthly Crop Production reports (see Figure B5.5, Annex B5.1) are issued on or close to the tenth day of each month, and reflect conditions as of the first day of the month;
- Weekly Crop Progress & Condition reports are issued on the first business day of each week, from April to November, and reflect the status and the conditions

[15] USDA-NASS-RSS VegScape: http://nassgeodata.gmu.edu/VegScape/
[16] For details on this model, see USDA-NASS 2012

existing as of the previous Sunday (e.g. farmer activities such as the progress of crop planting and harvesting through various phenological stages of crop development, pasture and range conditions, soil moisture ratings).

The USDA-NASS has developed a specific web platform (Ag Census Web Maps[17]) to provide the data from US agricultural censuses to the public (see Figure B5.6, Annex B5.1).

2.4. Human, financial, and technical infrastructure

The system consists of a pool of highly efficient national institutions, such as the USDA, the NOAA, and NASA. The USDA is investing in the application of new technologies such as remote sensing and GIS. Over 5,000 enumerators are part of the structure for conducting yield surveys. The use of crop-soil-weather simulation models probably present some constraints. However, all three institutions have very solid institutional, human and technological infrastructures.

2.5. Institutional structure and sustainability

Because the system is coordinated by the USDA, together with the NOAA and NASA, it is well-established and sustainable.

2.6. Innovation and integration with regional and global initiatives

The Global Agricultural Monitoring (GLAM[18]) Project (see Figure B5.7, Annex B5.1), jointly funded by the USDA and the NASA Applied Sciences Program, is updating the FAS decision support system with the new generation of observations from NASA satellites. The GIMMS MODIS' GLAM system is a web-based geographic application (see Figure B5.8, Annex B5.1) that offers MODIS imagery and user interface tools for data query and plotting MODIS NDVI time series. The system processes near real-time and science quality Terra and Aqua MODIS 8-day composite datasets. These datasets are derived from the MOD09 and MYD09 surface reflectance products, which are generated and provided by NASA/GSFC/EOSDIS LANCE and NASA/GSFC MODAPS. The GIMMS MODIS GLAM system is developed and provided by the NASA/GSFC/GIMMS group for the USDA/FAS/IPAD GLAM Project. The mission of the USDA/FAS/IPAD is to provide objective, timely, and regular assessments of the global agricultural production outlook and the conditions affecting global food security.

[17] Agricultural Census: http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Maps/
[18] GLAM: http://glam1.gsfc.nasa.gov/

3. Linking up with crop production forecasts: the practices followed by the USA's official national sources

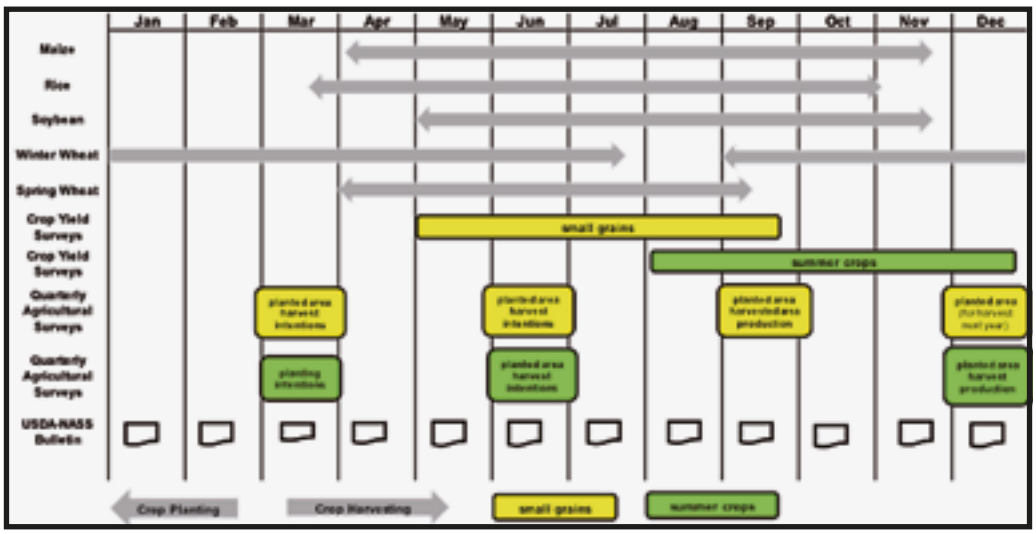
3.1. Which area data is used? The methodology used

The USDA expends considerable effort in determining US crop yields, as a service to the agricultural community. As mentioned above, the USDA-NASS conducts two large annual panel surveys, the AYS and the OYS, continuously throughout the growing season, to establish state- and national-level yield estimates. The AYS is based on a maintained "list frame" of farmers. The second is the OYS, and is conducted parallel to the AYS (see Section 2.1.2). The OYS derives an independent set of indications through biophysical crop measurements. For this purpose, hundreds of small plots are randomly sampled from fields throughout the major growing areas, which are visited by enumerators a number of times during the crop season. The attributes on which data are collected include plant counts per unit area, grain size, grain weight, etc. The information from all plot-level data is ultimately aggregated into a model to derive this second set of yield indications. The OYS is more limited in scope than the AYS, in that it only focuses on the dominant commodity crops such as corn, soybeans, wheat, potatoes and cotton. Ultimately, the results from both surveys and any relevant ancillary information are analysed by the NASS' Agricultural Statistics Board (ASB) to provide the monthly yield forecasts. Once the season is complete, late in the fall, an additional broad survey is undertaken to document agricultural production statistics down to the county level. For this purpose, questionnaires are sent to a much larger sample of producers, asking for responses on several agricultural aspects of their operation, including estimates of their crop yields. Finally, these county-level statistics are assessed and published, reconciled with the national- and state-level yields previously established by the ASB.

3.2. Release calendars: timeliness

The USDA strives to provide the agricultural community with estimates that are accurate, objective, reliable, and timely (USDA-NASS 1999). The Crop Production report is published no later than the 12th day of each month. Area, yield, and production forecasts and estimates are prepared for the crops in season. Table 5.1 below provides a complete description of the release frequency of yield forecasts and estimates, and acreage and production estimates in the USA, together with the planting and harvesting calendar of the main crops.

TABLE 5.1
Crop calendar and release frequency of crop forecasts and estimates



Source: USDA 1994, Holland 2011

3.3. Human, financial, and technical infrastructure

The system consists of a pool of highly efficient national institutions such as USDA, NOAA, NASA; see Section 2.3 above.

3.4. Institutional structure and sustainability

The system for computing area estimates is still coordinated by the USDA, together with the NOAA and the NASA. Therefore, it is well-established and sustainable.

Annex A1

Crop Yield: Key Concepts and Definitions

Crop yield is defined as the harvested crop mass per unit of area and is normally measured in kilograms (kg) or metric tons (t) of product per hectare:

$$Crop\ Yield = (amount\ of\ harvested\ product)/(crop\ area)$$

Thus, the estimation of crop yield requires an estimation of both the crop area and the quantity of product obtained from that area.

Different classifications of concepts and definitions have been proposed to discuss crop yield and, in some circumstances, similar terminology is used to indicate rather different concepts (Fermont and Benson, IFPRI, 2011).

A classification that may be useful in distinguishing different approaches to crop estimation and forecasting resorts to three different yield terminologies, namely:

- **Biological (or gross) yield**: the yield obtained before any losses occur during and after harvest.
- **Harvested yield**: the biological yield minus the losses that occurred during harvest. Generally, the gap between biological and harvested yield equals the quantity required as seed for next season's planting (Poate, 1988).
- **Economic yield**: the yield reflecting the quantity that farmers can use after the postharvest losses that may occur during cleaning, threshing, winnowing, and

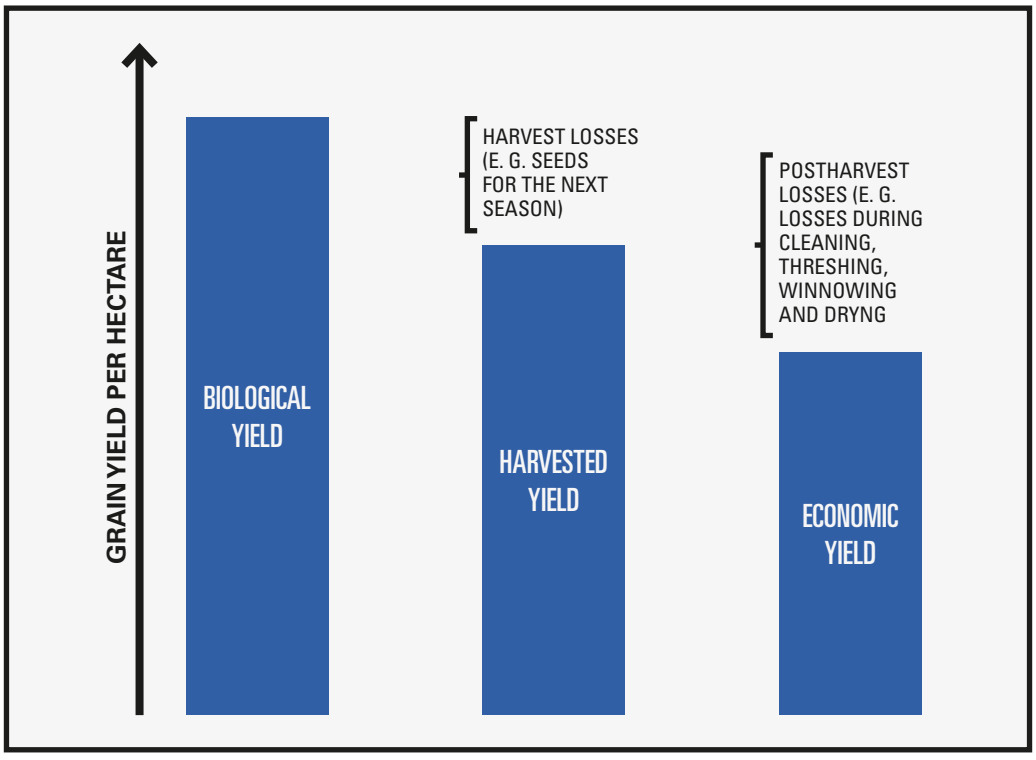
drying have been taken into account (Keita, 2003)[1].

An alternative classification relies upon the concept of yield gap Y_g, which is closely linked to the definition and measurement of the yield potential Y_p. Agronomists generally refer to three different levels of yield when modelling Y_g:

- **Yield potential Y_p**: the theoretical maximum yield that can be achieved in a given agro-ecological zone with a given cultivar. It assumes an ample supply of water, nutrients, or other yield-building factors and the complete absence of yield-reducing factors such as pests and diseases (Van et al., 2013).
- **Exploitable (or attainable) yield Y_e**: this takes into account growth-limiting factors such as nutrient deficiencies and water stress (Fermont and Benson, 2011).
- **Actual yield (or farmer yield) Y_a**: this takes into account growth-reducing factors such as radiation, temperature, water, nutrients, management practices, weeds, pests, diseases, and pollutants. It represents the yield that farmers obtain under normal management (Rabbinge, 1993).

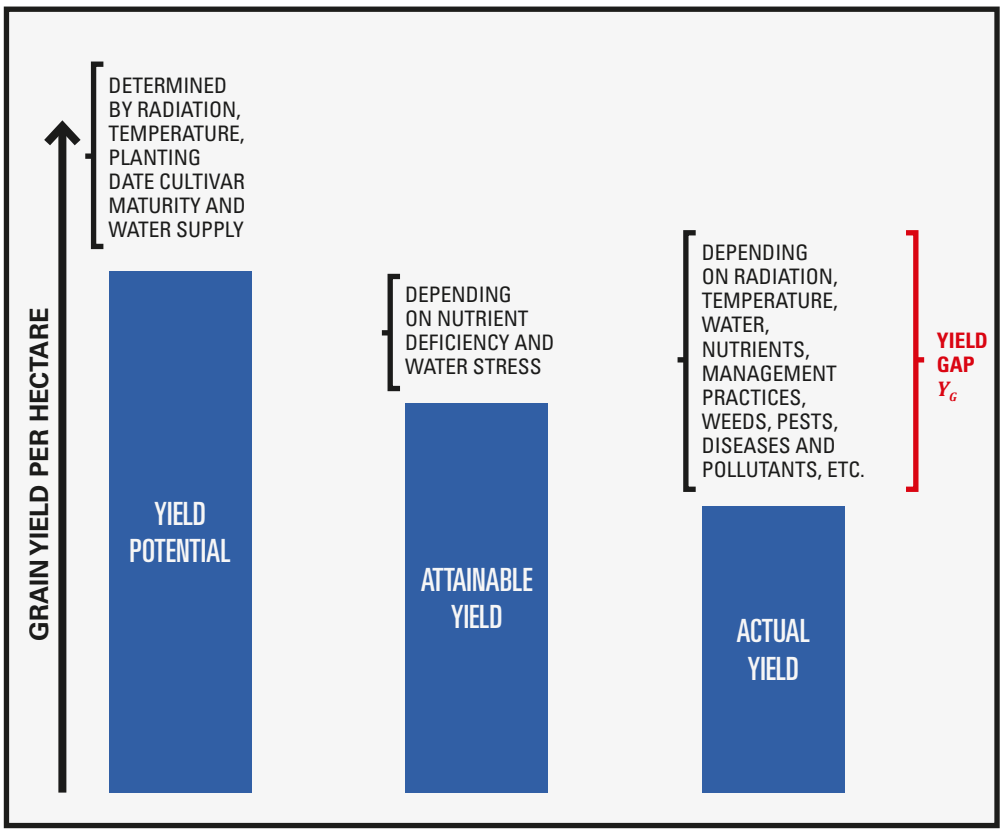
Thus, the yield gap is the difference between potential and actual yield (see Figure A1.2).

FIGURE A1.1
Classification of yield considering harvest and post-harvest losses



[1] Storage losses are normally not included in the definition of economic yield, even though they may be important to farmers (Fermont and Benson, 2011).

FIGURE A1.2
Classification of yield for the definition of the yield gap



Source: modified from Van Ittersum et al., 2013

Annex A2

Available Data Resources

Date of last access for all resources: 16 October 2015

Soil data and grids

- **ISRIC – World Soil Information**
  http://www.isric.org/content/data
- **FAO Soils Portal**
  http:/www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/en/
- **European Soil Portal – Soil Data and Information Systems**
  http://eusoils.jrc.ec.europa.eu/data.html
- **EuDASM (European Digital Archive on Soil Maps of the World)**
  http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/indexes/access.htm
- **GEOSS (Group on Earth Observations) Portal**
  http://www.geoportal.org/web/guest/geo_home_stp
- **Harmonized World Soil Database V. 1.2**
  http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/
- **Global SoilMap**
  http://www.globalsoilmap.net/

Meteorological data

- **USA-NOAA**
  http://www.noaa.gov/
- **Environment Canada**
  http://weather.gc.ca/
- **European Centre for Medium-Range Weather Forecasts**
  http://www.ecmwf.int/
- **Japan Meteorological Agency**
  http://www.jma.go.jp/jma/indexe.html

Climate data

- **The GOES Project**
  http://atmospheres.gsfc.nasa.gov/climate/
- **The Climate Change Knowledge Portal, The World Bank**
  http://sdwebx.worldbank.org/climateportal/
- **NASA Global Change Master Directory**
  http://gcmd.gsfc.nasa.gov/
- **IRI/LDEO Climate Data Library**
  http://iridl.ldeo.columbia.edu/

GIS Data Sources

- **Natural Earth**
  http://www.naturalearthdata.com/downloads/
- **USGS Earth Explorer**
  http://gisgeography.com/best-free-gis-data-sources-raster-vector/
- **NASA Socioeconomic Data and Application Center (SEDAC)**
  http://sedac.ciesin.columbia.edu/
- **UNEP Environmental Data Explorer**
  http://geodata.grid.unep.ch/

Time series and forecasts of crop yield data

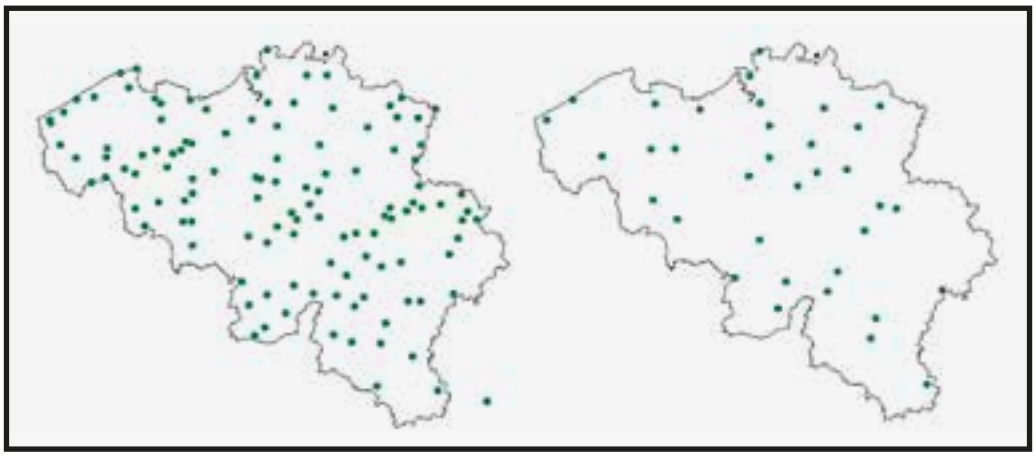
- **USDA Open Data Catalog**
  http://www.usda.gov/wps/portal/usda/usdahome?navid=data
- **FAOSTAT**
  http://faostat3.fao.org/home/E
- **OECD.Stat**
  http://stats.oecd.org/

Annex B1

Belgium

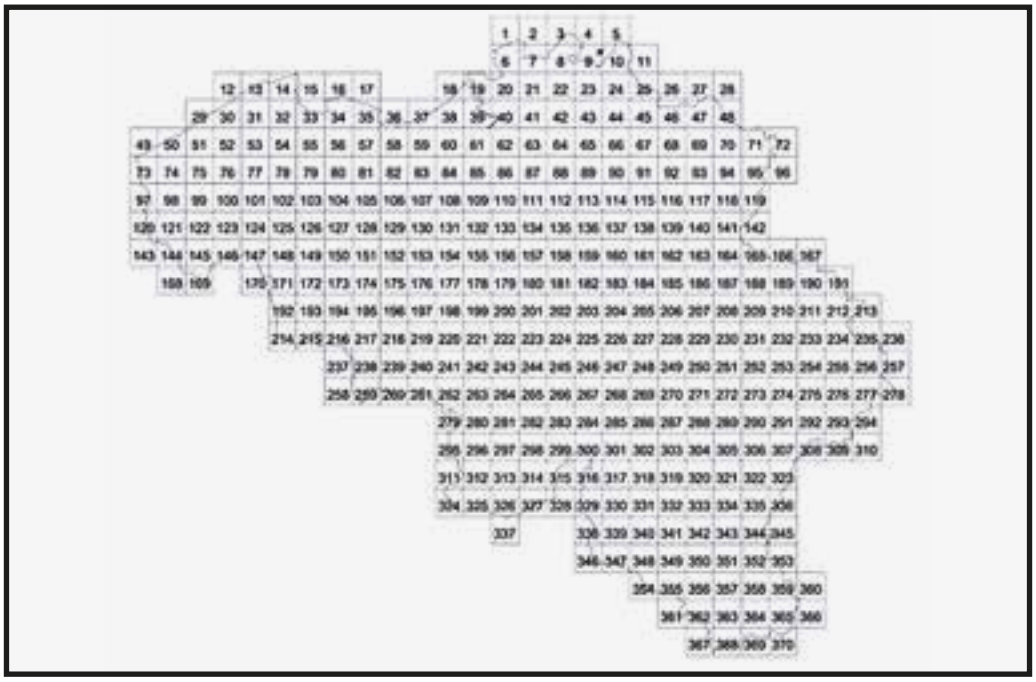
Annex B1.1 – Figures

FIGURE B1.1
Left map: meteorological stations used for historical records. Right map: meteorological stations used for the operational phase



Source: Tychon et al. 2000.

FIGURE B1.2
Grid covering the area of Belgium, composed of 370 cells of 10-km resolution each

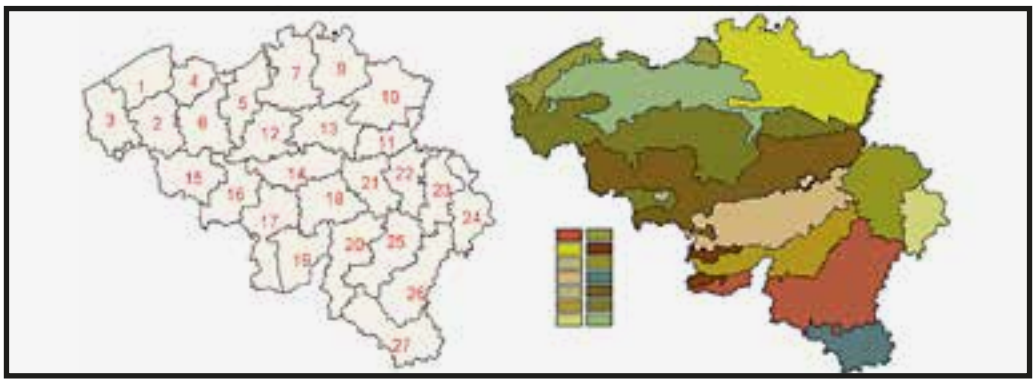


Source: Tychon et al., 2000

FIGURE B1.3
Map of the 17 pedological zones in Belgium

Source: Tychon et al. 2000

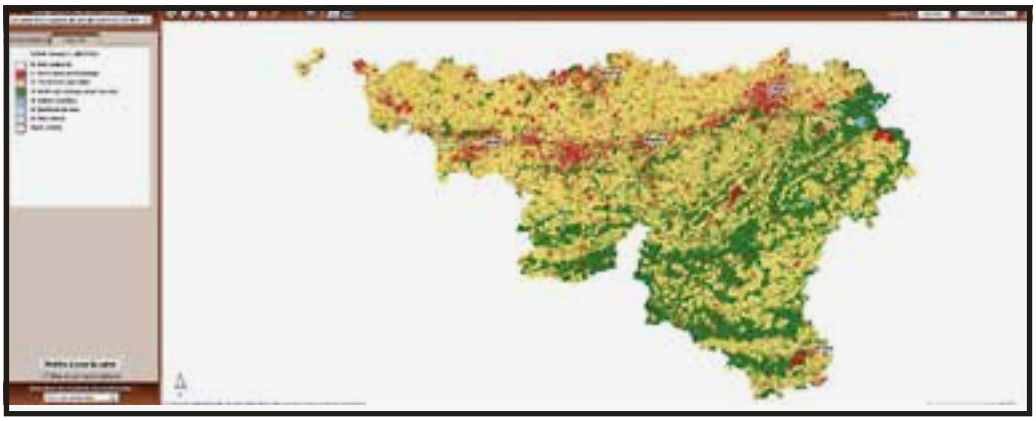
FIGURE B1.4
Administrative boundaries.
Left map: Agricultural circumscriptions. Right map: Agricultural regions.



Source: Tychon et al. 2000

Colour legend (from top left): Ardenne, Campine, Campine hennuyère, Condroz, Dunes, Famenne, Haute Ardenne, Polders, Région herbagère (Fagne), Région herbagère, Région jurassique, Région limoneuse, Région sablo-limoneuse, Région sablonneuse.

FIGURE B1.5
Land use in Wallonia

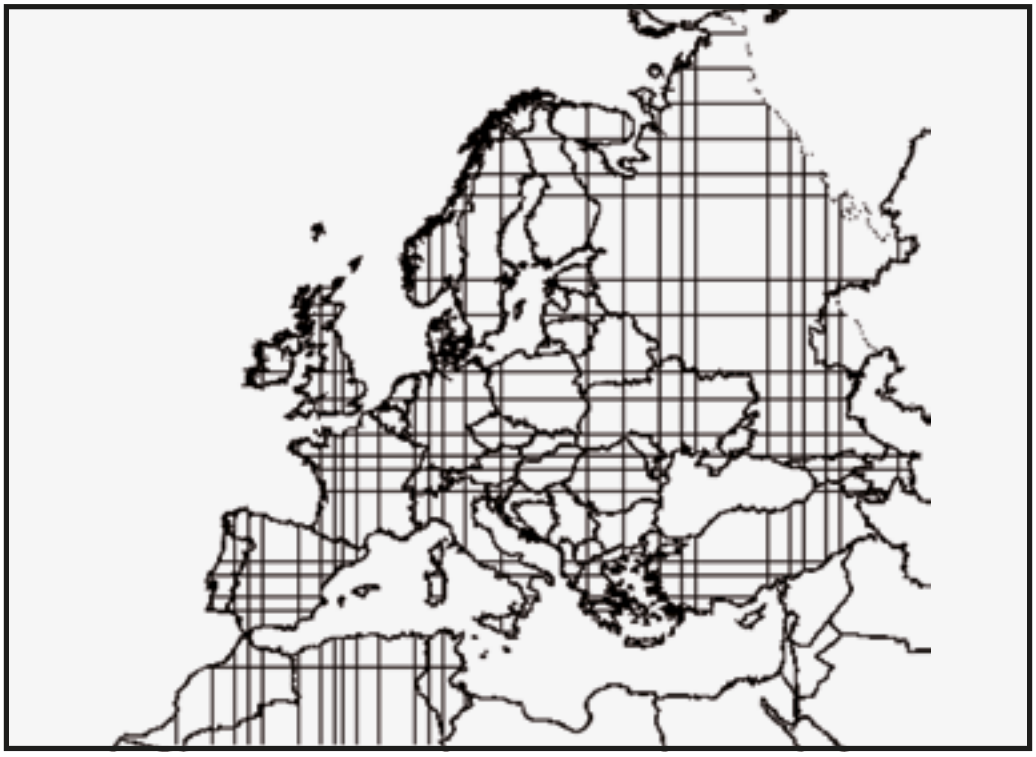


Source: http://cartopro3.wallonie.be/CIGALE/viewer.htm?APPNAME=COSW&APPMODE=VIEWE

Annex B1.2 - The JRC-MARS Crop Yield Forecasting System (MCYFS)

In 1992, the JRC developed the MARS Crop Yield Forecasting System (MCYFS), a crop yield forecasting system that provides timely forecasts of crop production – including biofuel crops – for Europe and other strategic areas (EU Countries, the Maghreb, the European part of Russia, Ukraine, and Belarus) (Figure 1 below). The MCYFS, which the JRC maintains to this day, monitors crop vegetation growth (for cereals, oil seed crops, protein crops, sugar beet, potatoes, pastures, and rice), including the short-term effects of meteorological events on crop production. It also provides seasonal yield forecasts for key European crops (wheat, maize, etc.).

FIGURE B1.6
Meteorological grid (50 x 50 km) of countries covered by the MCYFS



Source: http://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Main_Page

The MCYFS is an integrated analysis tool based on satellite observations of Earth, meteorological observations, meteorological forecasts, agro-meteorological and biophysical modelling, and statistical analyses. The MCYFS uses near-real time data, e.g. observed weather, weather forecasts and remote sensing data. At regular intervals, crop yield statistics are added. The static input data consists of soil maps, crop parameters and administrative regions. With these inputs, the data crop conditions can be simulated and crop-specific end-of-season yield forecasts may be computed. The MCYFS consists of a set

of methodologies and tools that are grouped into five modules: Weather monitoring, Remote sensing, Crop simulation, Yield forecasting, and Software tools (see Figure B.1.7. below).

The data processing within each of these modules enables qualitative and quantitative analyses throughout the cropping season and, ultimately, crop yield forecasts for major crops (Figure 3 below). It must be noted that expert decisions are fundamental at all steps of the processes. The MCYFS has three operational levels (see Figure B1.7 below): **Level I** (Level of weather data interpolation); **Level II** (Crop growth simulation and yield forecasting); and **Level III** (Level of aggregation in standard administrative units at various spatial scales).

A specific tool has been developed to integrate the crop yield indicators generated by modelling platforms and those derived from remote sensing information. The indicators generated from the various models are inserted into a statistical analysis platform that integrates different statistical approaches. Considering that manual analysis tends to give rise to errors, the CGMS Statistical Toolbox (CST) performs several analyses, such as time trend analyses, (multiple) regression analyses and scenario analyses. Each model is tested to ascertain whether it improves prediction beyond the trend only, and each hypothesis is tested to determine the significance of results (Figure B1.10 below).

FIGURE B1.7
The five MCYFS modules

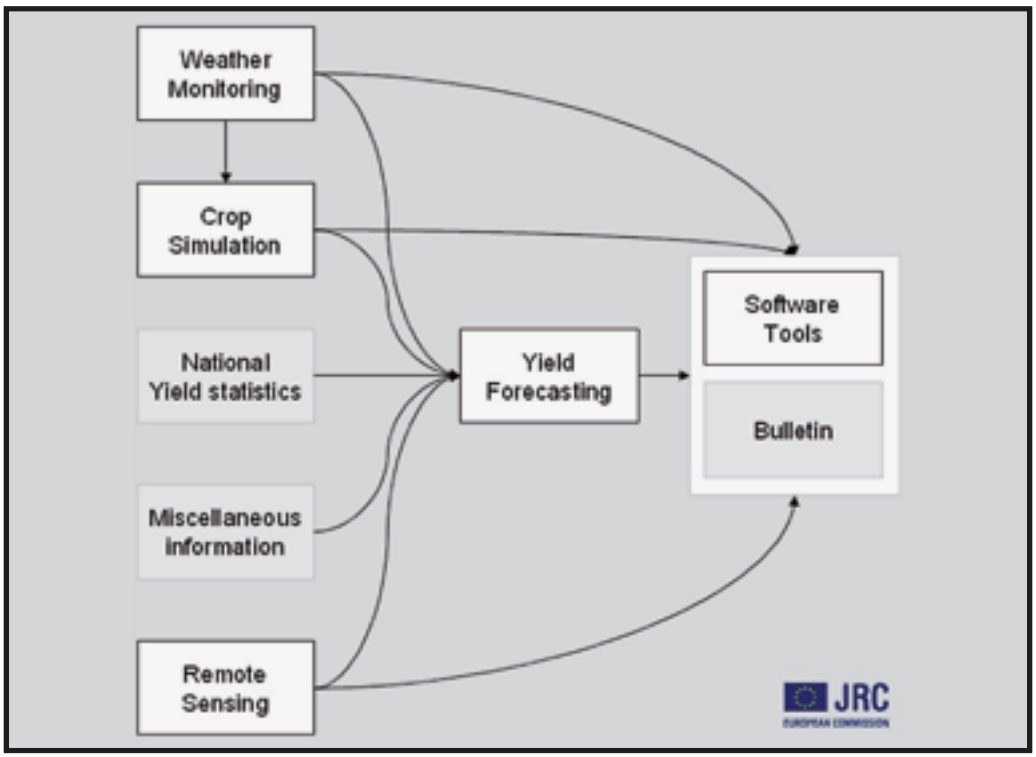


FIGURE B1.8
MCYFS: Synthetic schema

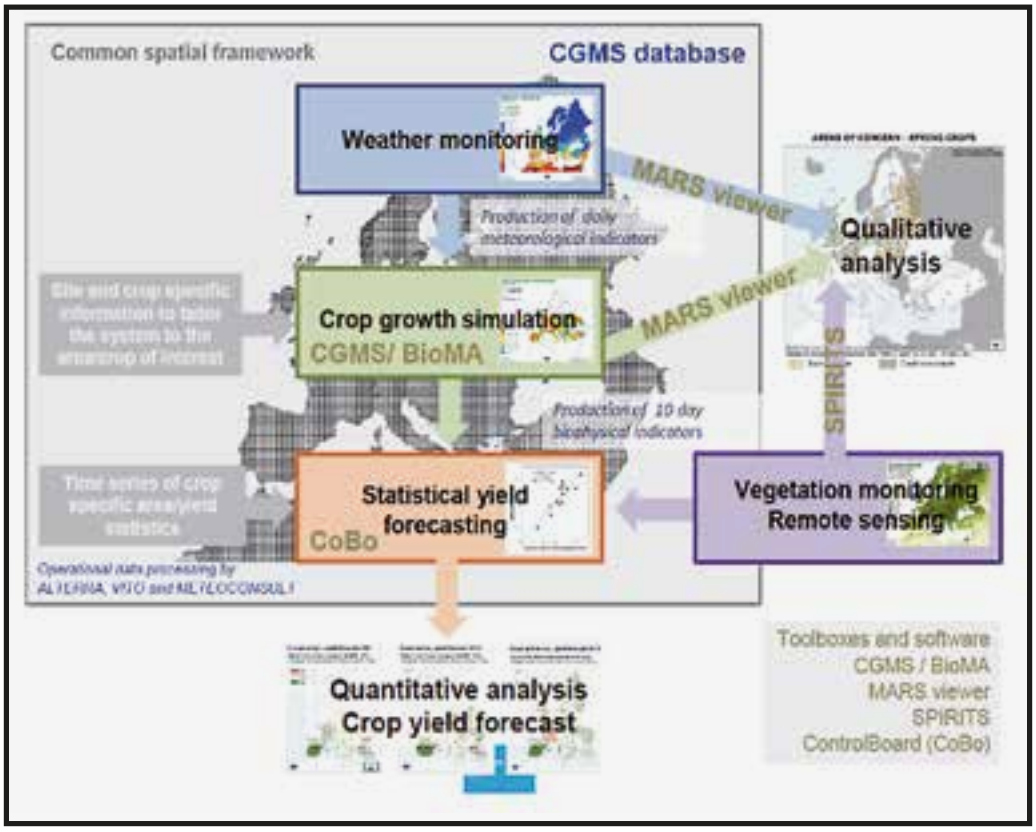
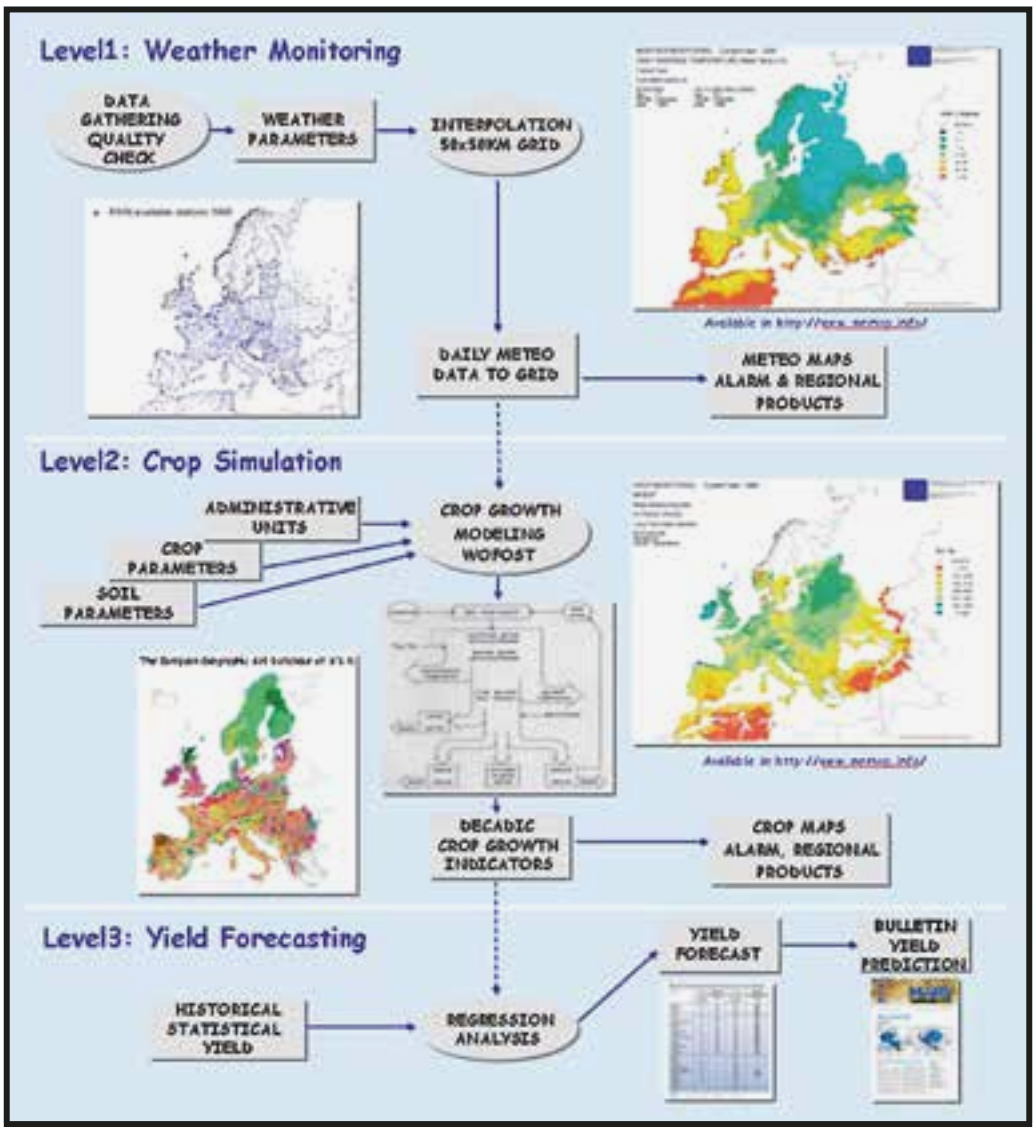
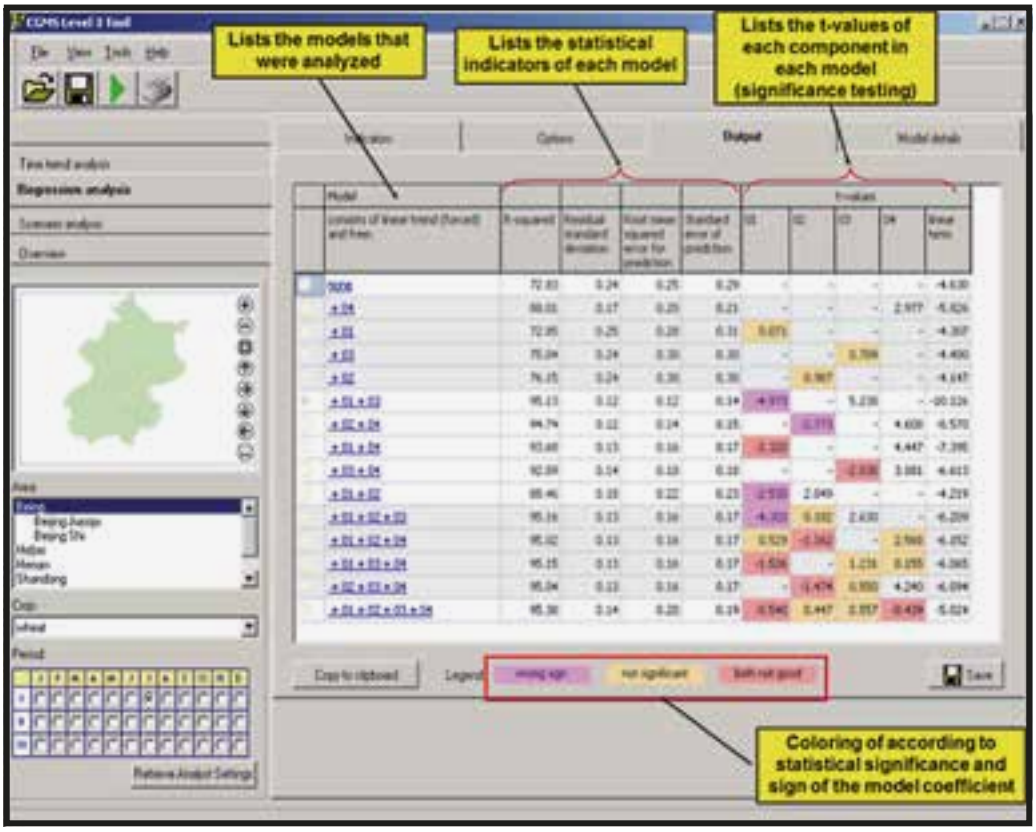


FIGURE B1.9
Descriptive schema of the MCFYS' three operational levels



Source: http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/Crop-Growth-Monitoring-System-CGMS

FIGURE B1.10
The CGMS Statistical Toolbox (CST)



Source: http://www.e-agri.info/pdf/D62.1_CST_Piloting_workshop.pdf

Annex B1.3 - Input Parameters used in the Belgian Crop Growth Monitoring System (B-CGMS)

TABLE B1.1

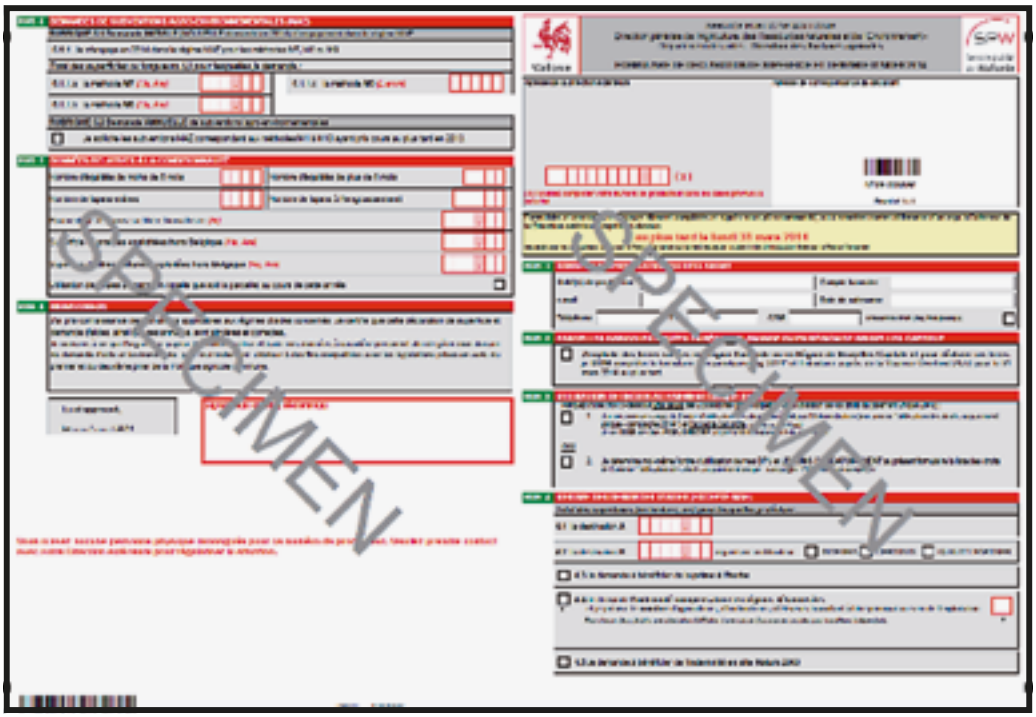
List of input parameters used in the B-CGMS

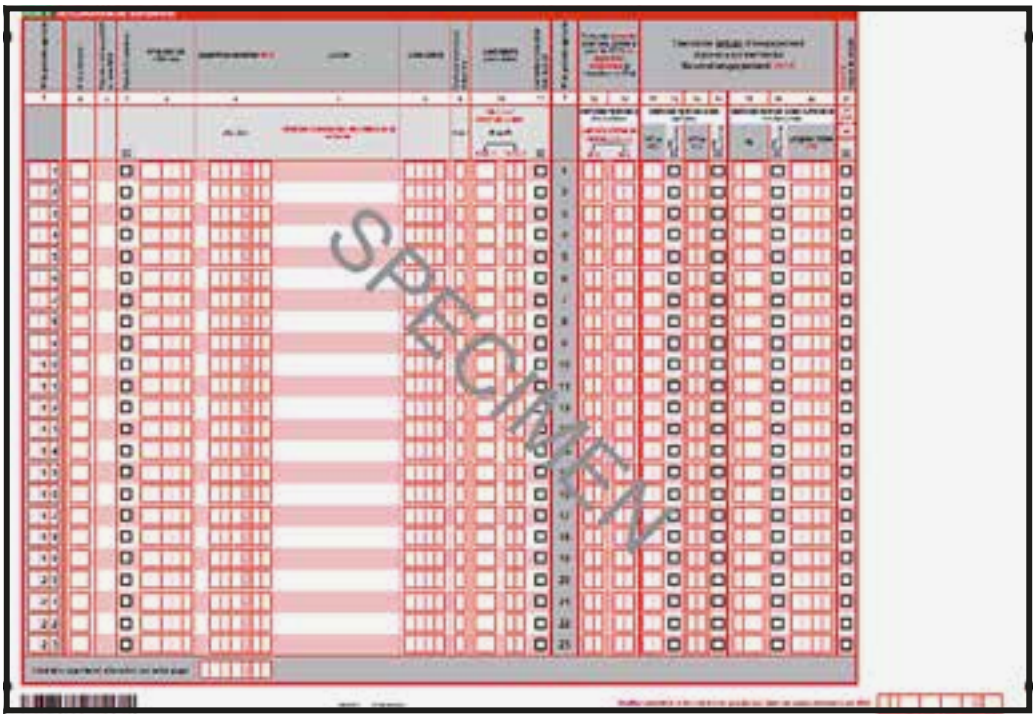
METEOROLOGICAL PARAMETERS		
Name	**Description**	**Unit**
MAXIMUM_TEMPERATURE	maximum air temperature	[°C]
MINIMUM_TEMPERATURE	minimum air temperature	[°C]
VAPOR_PRESSURE	mean daily vapour pressure	[hPa]
WINDSPEED	mean daily wind speed at 10 m height	[m.s-1]
RAINFALL	daily rainfall	[mm.d-1]
E0	daily transpiration of water surface	[mm.d-1]
ES0	daily transpiration of wet bare soil	[mm.d-1]
ET0	daily transpiration of crop canopy	[mm.d-1]
CALCULATED_RADIATION	daily radiation at surface	[KJ.m-2.d-1]
SNOW_DEPTH	daily mean snow depth	[cm]
CROP GROWTH MODEL PARAMETERS		
Name	**Description**	**Unit**
AMAXTB_01	max. leaf CO2 assim. rate as a function of DVS (Development Stage)	[kg ha^{-1} hr^{-1}/-]
CFET	correction factor transpiration rate	[-]
CVL	efficiency of conversion into leaves	[kg kg^{-1}]
CVO	efficiency of conversion into storage org.	[kg kg^{-1}]
CVR	efficiency of conversion into roots	[kg kg^{-1}]
CVS	efficiency of conversion into stems	[kg kg^{-1}]
DEPNR	crop group number for soil water depletion	[-]
DLC	critical daylength (lower threshold)	[hr]
DLO	optimum daylength for development	[hr]
DTSMTB_01	daily increase in temp. sum as a function of av. temp.	[°C/°C]
DVSEND	development stage at harvest (=2.0 at maturity)	[-]
EFF	light use effic. single leaf	[kg ha^{-1} hr^{-1} J^{-1} m^2 s]
FLTB_01	fraction of above-gr. dry matter to leaves as a function of DVS	[kg kg^{-1}/-]
FOTB_01	fraction of above-gr. dry matter to stor. org. as a function of DVS	[kg $kg^{-1/-}$]
FRTB_01	fraction of tot. dry matter to roots as a function of DVS	[kg kg^{-1}/-]
FSTB_01	fraction of above-gr. dry matter to stems as a function of DVS	[kg kg^{-1}/-]
IAIRDU	air ducts in roots present (=1) or not (=0)	[-]

IDSL	indicates whether pre-anthesis development dep. on temp.(0), dayl.(1), or both(2)	[-]
KDIF	extinction coefficient for diffuse visible light	[-]
LAIEM	leaf area index at emergence	[ha ha^{-1}]
PERDL	max. rel. death rate of leaves due to water stress	[-]
Q10	rel. incr. in resp. rate 10 Cel temp. incr.	[-]
RDI	initial rooting depth	[cm]
RDMCR	maximum rooting depth	[cm]
RDRRTB_01	relative death rate of stems as a function of DVS	[kg kg^{-1} d^{-1}/-]
RDRSTB_01	relative death rate of roots as a function of DVS	[kg kg^{-1} d^{-1}/-]
RFSETB_01	reduction factor for senescence as a function of DVS	[-/-]
RGRLAI	maximum relative increase in LAI	[ha ha^{-1} d^{-1}]
RML	rel. maint. resp. rate leaves	[kg CH2O kg^{-1} d^{-1}]
RMO	rel. maint. resp. rate stor. org.	[kg CH2O kg^{-1} d^{-1}]
RMR	rel. maint. resp. rate roots	[kg CH2O kg^{-1} d^{-1}]
RMS	rel. maint. resp. rate stems	[kg CH2O kg^{-1} d^{-1}]
RRI	maximum daily increase in rooting depth	[cm d^{-1}]
SLATB_01	specific leaf area as a function of DVS	[ha ha^{-1}/-]
SPA	specific pod area	[ha kg^{-1}]
SPAN	life span of leaves growing at 35 Celsius [d]	[-]
SSA	specific stem area	[ha kg^{-1}]
TBASE	lower threshold temp. for ageing of leaves	[°C]
TBASEM	lower threshold temp. for emergence	[°C]
TDWI	initial total crop dry weight	[kg ha^{-1}]
TEFFMX	max. effective temp for emergence	[°C]
TMNFTB_01	reduction factor of gross assim. rate as a function of low min. temp.	[°C]
TMPFTB_01	reduction factor for AMAX as a function of av. temp.	[°C]
TSUM1	temp. sum from emergence to anthesis	[°C]
TSUM2	temp. sum from anthesis to maturity	[°C]
TSUMEM	temp. sum from sowing to emerge.	[°C]
SOIL PARAMETERS		
Name	**Description**	**Unit**
HYDR_CONDUCT_SATUR	hydraulic conductivity of saturated soil	[cm d^{-1}]
MAX_PERCOL_ROOT_ZONE	maximum percolation rate root zone	[cm d^{-1}]
MAX_PERCOL_SUBSOIL	maximum percolation rate subsoil	[cm d^{-1}]
SEEPAGE_1_SHALLOW	1st topsoil seepage parameter for shallow seedbed	[-]
SEEPAGE_2_SHALLOW	2nd topsoil seepage parameter for shallow seedbed	[-]
SEEPAGE_1_DEEP	1st topsoil seepage parameter for deep seedbed	[-]
SEEPAGE_2_DEEP	2nd topsoil seepage parameter for deep seedbed	[-]
CRITICAL_AIR_CONTENT	critical soil air content for aeration	[cm-3.cm-3]
SOIL_MOISTURE_CONTENT_SAT	soil moisture content at saturation	[cm-3.cm-3]
SOIL_MOISTURE_CONTENT_WP	soil moisture content at wilting point	[cm-3.cm-3]
SOIL_MOISTURE_CONTENT_FC	soil moisture content at field capacity	[cm-3.cm-3]

Source: http://www.supit.net/, Appendix VII

Annex B1.4 - Crop Acreage Declaration form





Source: http://agriculture.wallonie.be/apps/spip_wolwin/IMG/pdf/Blanco_Agricole_2014_FR_-_Specimen-2.pdf

Annex B1.5 - Websites

Country	National Institutions	Link
Belgium	B-CGMS	http://b-cgms.cra.wallonie.be/
	Walloon Agricultural Research Centre	http://www.cra.wallonie.be/
	Belgian National Statistics Institute	http://statbel.fgov.be/fr/statistiques/chiffres/economie/agriculture/
	ULg	http://www.facsc.ulg.ac.be/cms/c_636656/en/arlon-campus-environnement-home
	VITO	https://vito.be/en
	IRM	http://www.meteo.be/meteo/view/en/65239-Home.html
	IRBAB	http://www.irbab-kbivb.be/
	FIWAP	www.fiwap.be
	COPF	http://www.cipf.be/fr/accueil.html
Link	**Int'l Organization**	**Link**
EU	JRC-Mars Unit	http://mars.jrc.ec.europa.eu/
	MCYFS	http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Crop-Monitoring-and-Yield-Forecasting
	WikiMCYFS	http://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Main_Page
	CGMS	http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/Crop-Growth-Monitoring-System-CGMS
	E-AGRI	http://www.e-agri.info/
	VITO	http://www.vito-eodata.be/PDF/portal/Application.html#Home
Group on Earth Observations	GEOGLAM	http://www.geoglam-crop-monitor.org/
FAO	FAOSTAT	http://faostat3.fao.org/home/E
	CLIMPAG	http://www.fao.org/nr/climpag/
WMO	AGMP Agricultural Meteorology Programme	http://www.wmo.int/pages/prog/wcp/agm/agmp_en.php

Annex B2

China

Annex B2.1 - Reports on Crop Production in China

TABLE B2.1
People's Republic of China National Bureau of Statistics' Report on Crop Production

I. INTENTION SURVEY				
ID	**Reporting date**	**Category**	**Reporter**	**Method**
N_I1	By March 10	Survey on crop planting intentions for the whole year	NBS survey office in each province	Sample survey
N_I2	By September 30	Survey on autumn and winter planting intentions	NBS survey office in each province	Sample survey
II. SOWN AREA REPORT				
ID	**Reporting date**	**Category**	**Reporter**	**Method**
N_A1	By May 15	Estimated sown area of early rice	NBS survey office in each province	Sample survey
N_A2	By June 30	Estimated sown area of early rice for major grain-producing counties	NBS survey offices in major crop production provinces (autonomous regions and municipalities)	Sample survey
N_A3	By June 30	Estimated sown area of cotton	NBS survey offices in Hebei, Jiangsu, Anhui, Shandong, Henan, Hubei, Hunan and Xinjiang	Sample survey
N_A4	By July 15	Estimated sown area of maize and mid-rice	NBS survey office in each province	Sample survey

N_A5	By August 25	Seasonal report on estimated sown area of all economic crops for the whole year (including cotton and rapeseed)	Statistical bureau in each province (autonomous region and municipality)	Complete reporting system
N_A6	By August 25	Estimated sown area of all autumn grain crops (including mid-rice, late rice, maize and soybean)	NBS survey office in each province	Sample survey
N_A7	By August 30	Estimated sown area of maize and mid-rice for major grain-producing counties	NBS survey offices in major crop production provinces (autonomous regions and municipalities)	Sample survey
N_A8	By October 30	Estimated sown area of all autumn crops (including mid-rice, late rice, maize and soybean) for major grain-producing counties	NBS survey offices in major crop production provinces (autonomous regions and municipalities)	Sample survey
N_A9	By November 30	Estimated autumn and winter sown area of summer crops (including winter wheat and spring wheat)	NBS survey offices in Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan, Shaanxi, Gansu, Ningxia and Xinjiang	Sample survey
N_A10	By December 30		NBS survey offices in Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou and Yunnan	Sample survey
N_A11	By December 30	Estimated sown area of winter rapeseed	Statistical bureau in each province (autonomous region and municipality)	Complete reporting system
N_A12	By January 30 of next year	Estimated autumn and winter sown area of summer crops for major grain-producing counties	NBS survey offices in major crop production provinces (autonomous regions and municipalities)	Sample survey
N_A13	Same as timeline of sample survey above	Estimated crop sown area of agricultural operation establishments	Statistical bureau in each province (autonomous region and municipality)	Complete reporting system
III. PRODUCTION ESTIMATES				
ID	**Reporting date**	**Category**	**Reporter**	**Method**
N_P1	First estimate by May 15, final estimate by June 15	Estimated production of winter rapeseed	Statistical bureau in each province (autonomous region and municipality)	Complete reporting system
N_P2	First estimate by May 25, final estimate by June 20	Estimated production of summer crops (including winter wheat and spring wheat)	NBS survey offices in Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou and Yunnan	Sample survey
N_P3	First estimate by Jun. 15, final estimate by June 30		NBS survey offices in Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan and Shaanxi	Sample survey
N_P4	First estimate by Jun. 30, final estimate by July 25		NBS survey offices in Gansu, Ningxia and Xinjiang	Sample survey

N_P5	By June 30	Estimated production of summer crops for major grain-producing counties	NBS survey offices in Jiangsu, Anhui, Xiangxi, Hubei, Hunan and Sichuan	Sample survey
N_P6	By July 10		NBS survey offices in Hebei, Liaoning, Shandong and Henan	Sample survey
N_P7	First estimate by Jul. 20, final estimate by August 10	Estimated production of early rice	NBS survey office in each province	Sample survey
N_P8	By August 20	Estimated production of early rice for major grain-producing counties	NBS survey offices in major crop production provinces (autonomous regions and municipalities)	Sample survey
N_P9	First estimate by September 5, final estimate by November 20	Estimated production of cotton	NBS survey offices in Hebei, Jiangsu, Anhui, Shandong, Henan, Hubei, Hunan and Xinjiang	Sample survey
N_P10	First estimate by September 25, final estimate by October 20	Estimated production of autumn crops	NBS survey offices in Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai and Ningxia	Sample survey
N_P11	First estimate by September 25, final estimate by November 20		NBS survey offices in Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Xizang and Xinjiang	Sample survey
N_P12	By November 20	Estimated production of all economic crops for the whole year	Statistical bureau in each province (autonomous region and municipality)	Complete reporting system
N_P13	By November 30	Estimated production of autumn crops for major grain-producing counties	NBS survey offices in major crop production provinces (autonomous regions and municipalities)	Sample survey
N_P14	By January 5 of next year	Annual report on grain crop production	NBS survey office in each province	Sample survey
N_P15	By February 15 of next year	Annual report on crop production of economic crops	Statistical bureau in each province (autonomous region and municipality); the cotton production of Hebei, Jiangsu, Anhui, Shandong, Henan, Hubei, Hunan and Xinjiang is reported by the NBS survey offices in the corresponding provinces	Complete reporting system, sample survey
N_P16	By February 15 of next year	Annual report on production of tropical and subtropical crops in five provinces in southern China	Statistical bureaus in Guangdong, Guangxi, Hainan, Fujian and Yunnan provinces	Complete reporting system
N_P17	By February 15 of next year	Annual report on production of tea, fruits and edible nuts	Statistical bureau in each province (autonomous region and municipality)	Complete reporting system

IV. OFFICIAL RELEASES OF CROP PRODUCTION				
ID	**Reporting date**	**Category**	**Reporter**	**Method**
N_R1	By middle of July	Official release of total production of summer grains (including winter wheat and spring wheat)	NBS Press Release	Sample survey Complete reporting system RS technique
N_R2	By end of August	Official release of production of early rice		
N_R3	By early of December	Official release of production of national grains for the whole year (including wheat, maize, rice and beans)		
N_R4	By middle of December	Official release of production of cotton		
N_R5	By end of February of next year	Official release of production of all crops		

Source: NBS, 2014

TABLE B2.2
People's Republic of China Ministry of Agriculture's Report on Crop Production

I. INTENTION SURVEY				
ID	**Reporting date**	**Category**	**Reporter**	**Method**
M_I1	By January 29	Survey on crop planting intentions for the whole year	Agricultural department (bureau) in each province (autonomous region and municipality) and their sample survey counties	Sampling survey
M_I2	By September 30	Survey on autumn and winter planting intentions (including winter wheat and rapeseed)	Agricultural departments (bureaus) in sample counties in Beijing, Tianjin, Hebei, Shanxi, Liaoning, Shandong, Henan, Shaanxi, Gansu, Ningxia, Xinjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Fujian, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou and Yunnan Provinces (autonomous regions and municipalities)	Sampling survey
II. SOWN AREA REPORT				
ID	**Reporting date**	**Category**	**Reporter**	**Method**
M_A1	By May 30	Estimated spring sown area (including early rice, spring wheat, maize, soybean and cotton)	Agricultural department (bureau) in each province (autonomous region and municipality)	Complete reporting system
M_A2	By June 30	Estimated crop sown area for the whole year	Agricultural departments (bureaus) at sample counties in each province (autonomous region and municipality)	Sampling survey
M_A3	By August 25		Agricultural department (bureau) in each province (autonomous region and municipality)	Complete reporting system

M_A4	By November 26	Estimated autumn and winter sown area (including winter wheat and rapeseed)	Agricultural departments (bureaus) in Beijing, Tianjin, Hebei, Shanxi, Liaoning, Shandong, Henan, Shaanxi, Gansu, Ningxia and Xinjiang	Complete reporting system
M_A5	By December 27		Agricultural departments (bureaus) in Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Fujian, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou and Yunnan	Complete reporting system
III. PRODUCTION ESTIMATES				
ID	**Reporting date**	**Category**	**Reporter**	**Method**
M_P1	By May 10 and June 20	Estimated production of summer grain and oil crops (including winter wheat and rapeseed)	Agricultural departments (bureaus) at sample counties in Beijing, Tianjin, Hebei, Shanxi, Liaoning, Shandong, Henan, Shaanxi, Gansu, Ningxia, Xinjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Fujian, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou and Yunnan Provinces (autonomous regions and municipalities)	Sampling survey
M_P2	By June 30		Agricultural departments (bureaus) in Beijing, Tianjin, Hebei, Shanxi, Liaoning, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Ningxia and Xinjiang	Complete reporting system
M_P3	By June 30	Estimated production of spring wheat	Agricultural departments (bureaus) at sample counties in Heilongjiang, Inner Mongolia, Qinghai, Xinjiang Ningxia and Gansu Provinces (autonomous regions and municipalities)	Sampling survey
M_P4	By June 30	Estimated production of early rice	Agricultural departments (bureaus) at sample counties in Zhejiang, Anhui, Jiangxi, Fujian, Hubei, Hunan, Guangdong, Guangxi, Hainan, Sichuan and Yunnan Provinces (autonomous regions and municipalities)	Sampling survey
M_P5	By July 30		Agricultural departments (bureaus) in Zhejiang, Anhui, Jiangxi, Fujian, Hubei, Hunan, Guangdong, Guangxi, Hainan, Sichuan and Yunnan	Complete reporting system
M_P6	By September 24	Estimated production of autumn crops (including middle rice, late rice, maize, soybean and cotton)	Agricultural departments (bureaus) at sample counties in each Province (autonomous region and municipality)	Sampling survey

M P7	– By October 25	Estimated crop production for the whole year	Agricultural departments (bureaus) in Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai and Ningxia	Complete reporting system
M P8	– By November 25		Agricultural departments (bureaus) in Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan and Xinjiang	Complete reporting system
M P9	_ By February of next year	Annual report on production of major crops	Agricultural department (bureau) in each province (autonomous region and municipality)	Complete reporting system
M P10	_ By February of next year	Annual report on production of tea, fruits and edible nuts		Complete reporting system
M P11	_ By February of next year	Annual report on vegetable production		Complete reporting system
M P12	_ By February of next year	Annual report on production of tropical and subtropical crops in five provinces in southern China	Agricultural departments (bureaus) in Guangdong, Guangxi, Hainan, Fujian and Yunnan	Complete reporting system

Source: MoA, 2013

TABLE B2.3

Crop reporting dates from NBS, MoA and CMA against the crop calendar

Months	Jan.			Feb.			Mar.			Apr.			May			June			July			Aug.			Sept.			Oct.			Nov.			Dec.		
Dek	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Wheat (Winter)			M_I1				N_I1			C_V1			M_P1	C_Y1				M_A2, M_P2	N_R1					M_A3			M_I2, N_I2			M_P7			N_A9, M_A4, M_P8	N_R3		N_A10, M_A5
Wheat (Spring)			M_I1				N_I1								M_A1			M_A2, M_P3	N_R1					M_A3						M_P7			N_A9, M_P8	N_R3		N_A10
Maize (Spring)			M_I1				N_I1								M_A1			M_A2	N_A4, C_V3			C_V3		N_A6, M_A3,			M_P6			N_A8, M_P7			M_P8	N_R3		
Maize (Summer)			M_I1				N_I1								M_A1			M_A2	N_A4, C_V3			C_V3		N_A6, M_A3,			M_P6			N_A8, M_P7			M_P8	N_R3		
Rice (Early)			M_I1				N_I1						N_A1		M_A1		C_V2	N_A2, M_A2, M_P4		C_V2	M_P5			M_A3, N_R2						M_P7			M_P8	N_R3		
Rice (Middle)			M_I1				N_I1											M_A2	N_A4, C_V3			C_V3		N_A6, M_A3			M_P6			N_A8, M_P7			M_P8	N_R3		
Rice (Late)			M_I1				N_I1											M_A2						N_A6, M_A3			M_P6	C_V4	C_Y4	N_A8, M_P7			M_P8	N_R3		
Soybean			M_I1				N_I1								M_A1			M_A2		C_V3			C_V3	N_A6, M_A3			M_P6			N_A8, M_P7			M_P8	N_R3		
Cotton			M_I1				N_I1								M_A1			N_A3, M_A2		C_V3			C_V3	N_A5, M_A3			M_P6			M_P7			M_P8		N_R4	
Rapeseed			M_I1				N_I1			C_V1				C_Y1			M_P1	M_A2, M_P2						N_A5, M_A3			M_I2, N_I2			M_P7			M_A4, M_P8			N_A11, M_A5

Legend: Green block (▬) stands for the sowing seasons of specific crops; Yellow block (▬) stands for the harvest season of specific crops. **The PURPLE text** indicates the planting intentions of different organizations; the **BLUE text** indicates the estimated results from different organizations; the **ORANGE text** indicates the forecasted results from different organizations; the **RED text** indicates the official releases from the NBS. **N_I**, **N_A** and N_R respectively refer to the reporting date of crop planting intentions, sowing Area and official Release date of crop production from NBS (first column in Table B2.1 above). **M_I**, **M_A** and **M_P** respectively indicate the reporting date of planting Intention, sowing Area and crop Production from the MoA's system (first column in Table B2.2). **C_V** and C_**Y** respectively indicate the reporting date of yield Variation and Yield forecasts from the CMA's system (first column in Table 2.1).

Annex B2.2 – Websites

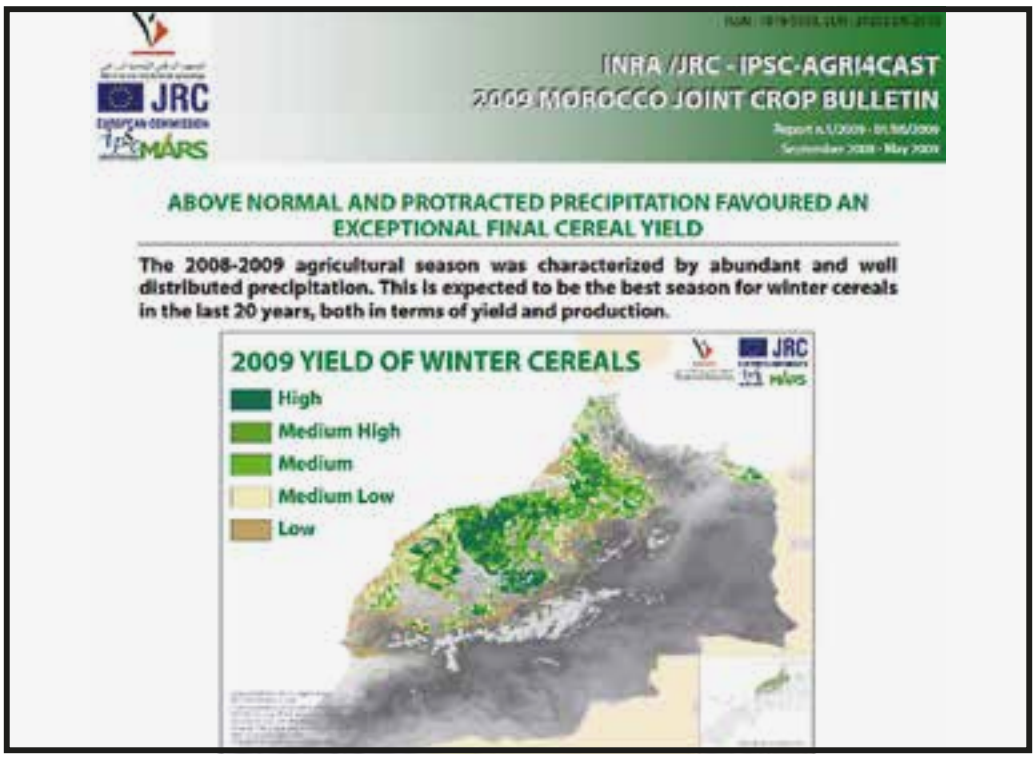
Country	National Institutions	Link
China	China Grain Net	http://www.cngrain.com/
	CMA	http://www.cma.gov.cn/en2014/
	CropWatch	http://www.cropwatch.com.cn/htm/en/index.shtml
	MoA	http://english.agri.gov.cn/
	NBS	http://www.stats.gov.cn/english/
Name	**Int'l Organization**	**Link**
EU	JRC-Mars Unit	http://mars.jrc.ec.europa.eu/
	MCYFS	http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Crop-Monitoring-and-Yield-Forecasting
USA	FASS-USDA	http://www.fas.usda.gov/data/world-agricultural-production

Annex B3

Morocco

Annex B3.1 – Figures

FIGURE B3.1
Agrometeorological bulletin for 2008-2009 season

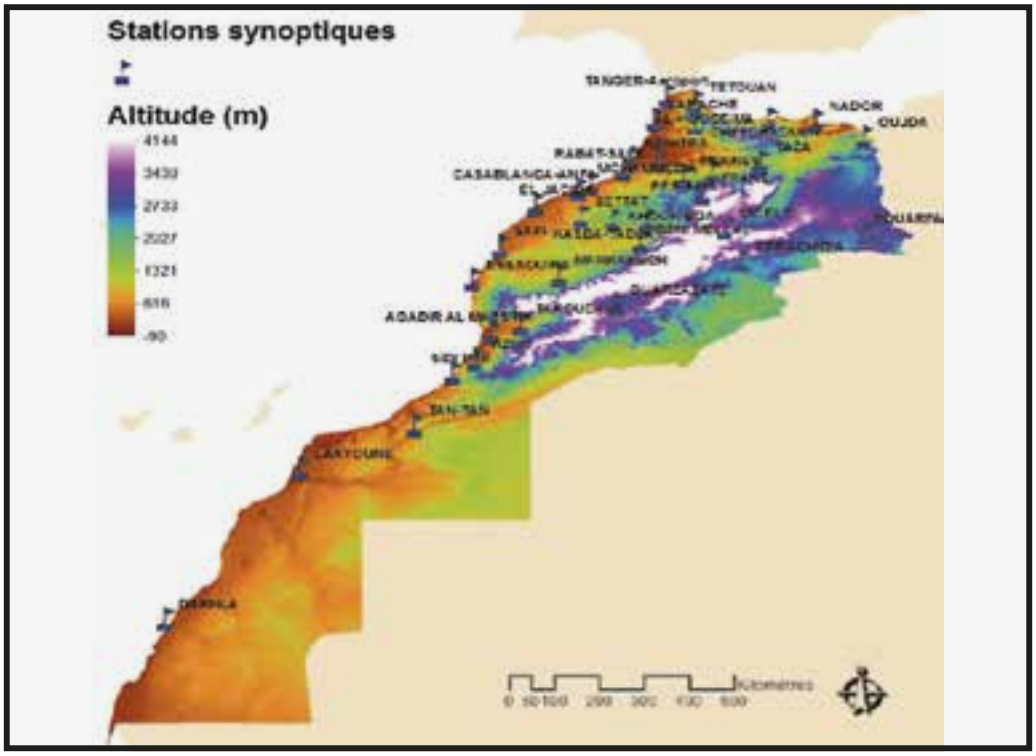


Source: JRC-MARS (ftp://mars.jrc.ec.europa.eu/bulletin/Europe/2009/MoBul09_03_English.pdf).

FIGURE B3.2
Agrometeorological bulletin for 2012-2013 cropping season

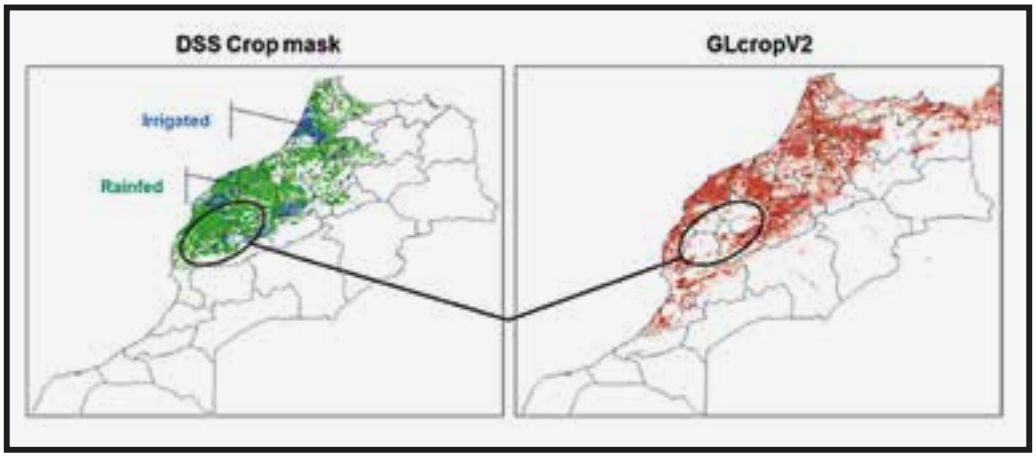
Source: CGMS-MAROC http://www.inra.ma/docs.asp?codedocs=139&codelangue=23).

FIGURE B3.3
The network of synoptic meteorological stations



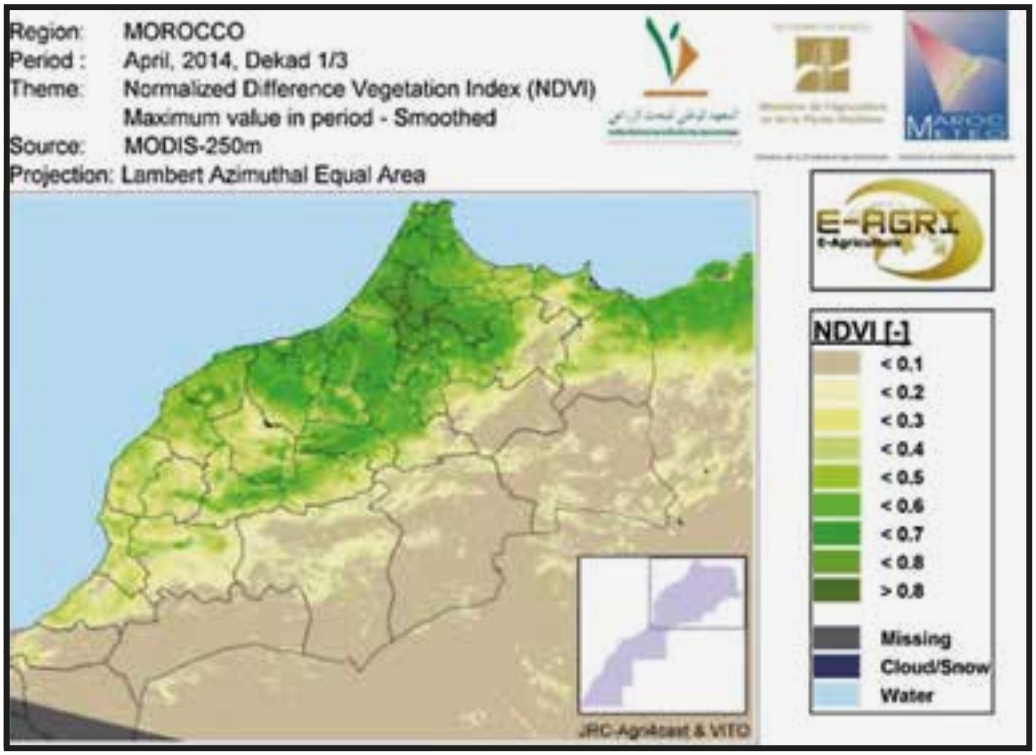
Source: Balaghi et al., 2013.

FIGURE B3.4
The difference between the DSS crop mask and the GlcropV2 dataset



Source: El Hairech et al., FP7-E-Agri meeting 2014, fourth Powerpoint presentation (http://www.e-agri.info/meetings/meeting_07_presentations.html).

FIGURE B3.5
The NDVI from MODIS (resolution: 250 m)

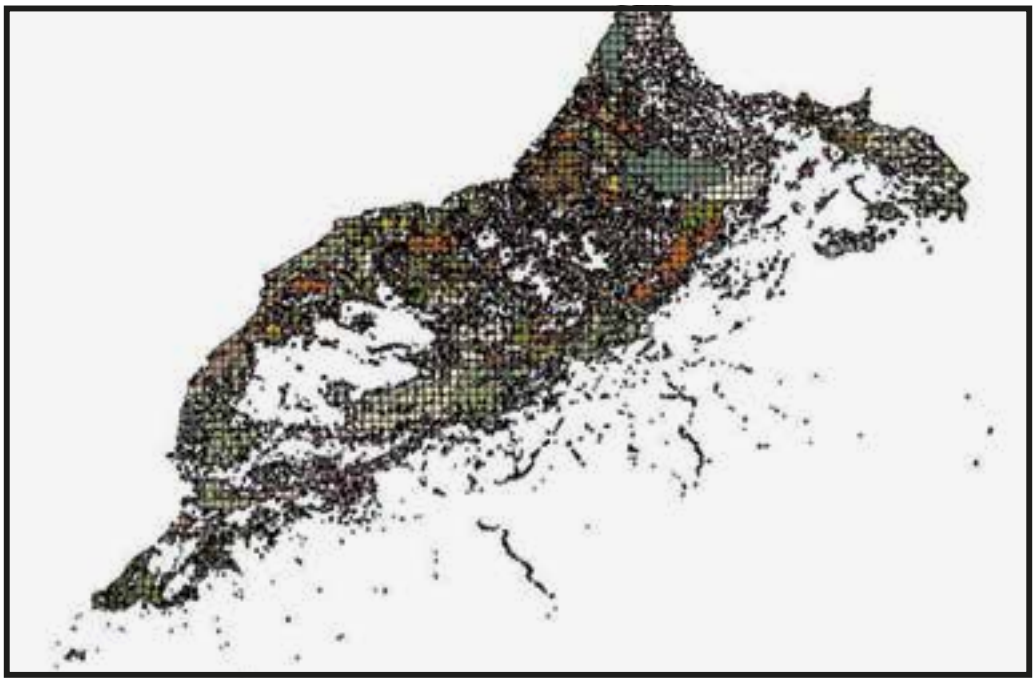


Source: Balaghi et al., 2013 (http://modis.gsfc.nasa.gov/data/dataprod/).

FIGURE B3.6
CGMS-MAROC's web-mapping tool for visualizing NDVI data

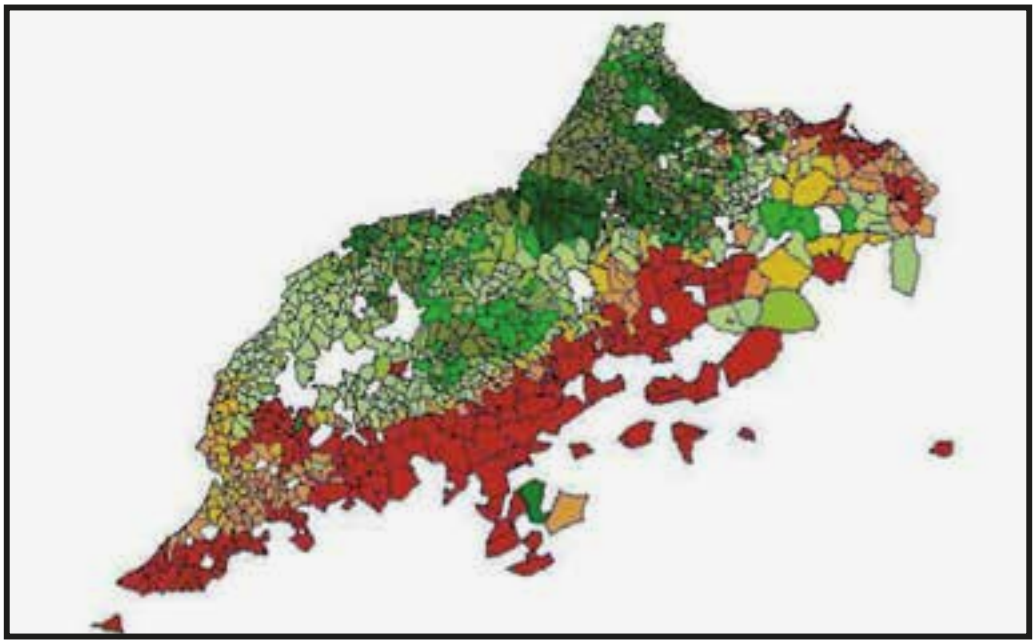
Source: http://www.cgms-maroc.ma/cgms-map/.

FIGURE B3.7
The EMUs used in CGMS-MAROC as inputs for Level 2



Source: Balaghi et al., 2013.

FIGURE B3.8
Example of WOFOST outputs aggregated to NUTS Level 3 for soft wheat

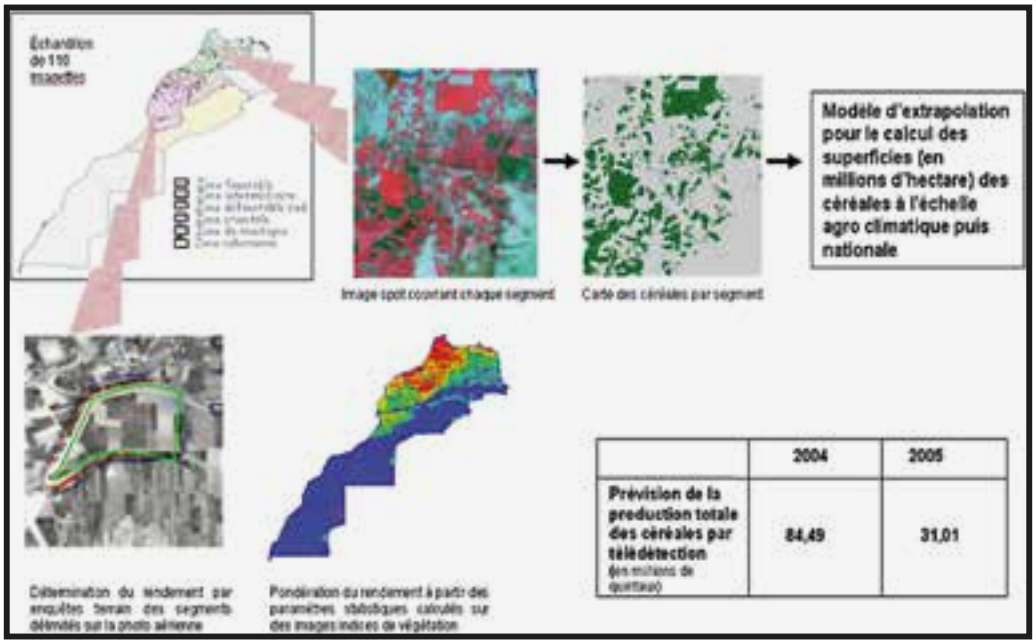


Source: Balaghi et al., 2013.

FIGURE B3.9
CGMS-MAROC's web server

Source: http://www.cgms-maroc.ma/cgms-map/

FIGURE B3.10
Crop production forecast by means of remote sensing

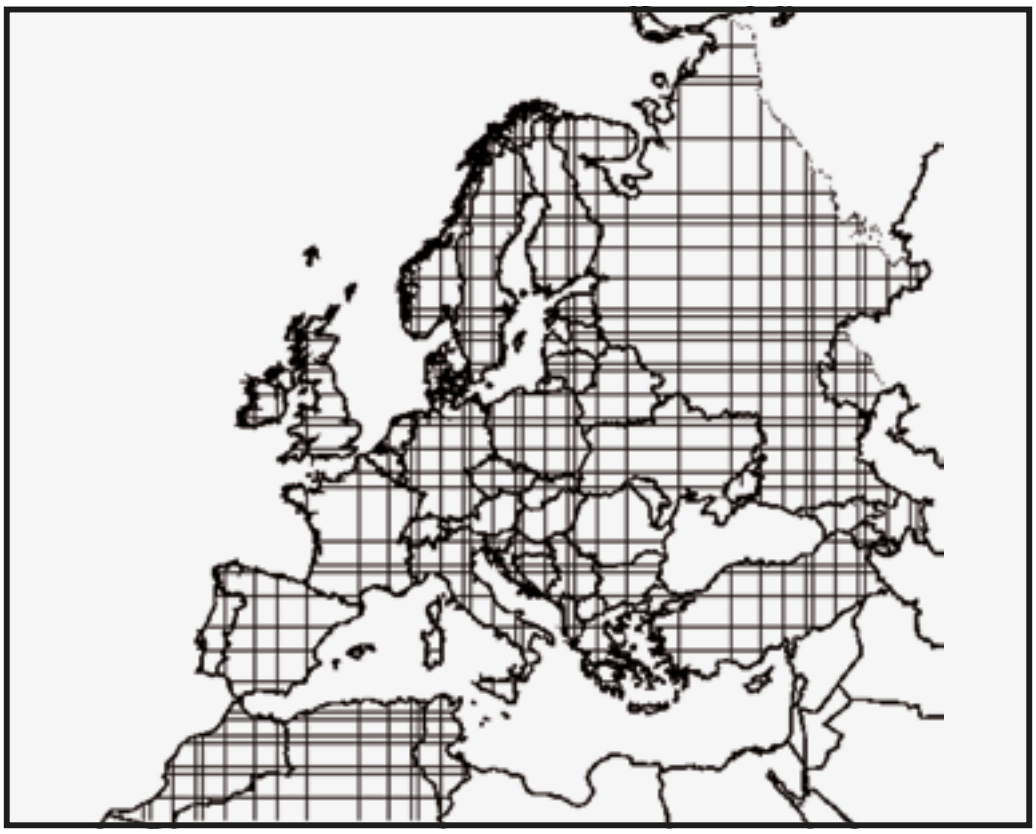


Source: http://www.crts.gov.ma/thematiques/agriculture/prevision-de-la-production-agricole.

Annex B3.2 - The JRC-MARS Crop Yield Forecasting System (MCYFS)

As mentioned above (see Annex B.1.2), the JRC has developed the MCYFS, a crop yield forecasting system that provides timely forecasts of crop production, including biofuel crops, for Europe and other strategic areas (EU Countries, Maghreb, European part of Russia, Ukraine, Belarus) (Figure B.3.11 below). The MCYFS monitors crop vegetation growth (cereals, oil seed crops, protein crops, sugar beet, potatoes, pastures, rice), including the short-term effects of meteorological events on crop production. It also provides seasonal yield forecasts of key European crops (wheat, maize, etc.).

FIGURE B3.11
Meteorological grid (50 x 50 km) of countries covered by the MCYFS



The MCYFS is an integrated analysis tool based on satellite observations of Earth, meteorological observations, meteorological forecasts, agro-meteorological and biophysical modelling, and statistical analyses. The MCYFS uses near-real time data such as observed weather, weather forecasts and remote sensing data. At regular intervals, crop yield statistics are added. Static input data consist of soil maps, crop parameters and administrative regions. With these input data, crop conditions can be simulated and crop specific end-of-season yield forecasts made. The MCYFS consists of a set of methodologies and tools grouped into five modules: Weather monitoring, Remote sensing, Crop simulation, Yield forecasting, Software tools (Figure B3.12).

The data processing within each of these modules enables qualitative and quantitative analyses during the cropping season and, ultimately, crop yield forecasts for major crops (Figure B3.13). It is important to note that the decisions made by the experts involved in the project are fundamental at all steps of the processes. The MCYFS has three operational levels (Figure B3.14): Level I (Level of weather data interpolation); Level II (Crop growth simulation and yield forecasting); Level III (Level of aggregation in standard administrative units at various spatial scales).

A specific tool was developed to integrate the crop yield indicators generated by modelling platforms and those derived from remote sensing information. The indicators generated

from the various models are inserted into a statistical analysis platform that must integrate different statistical approaches. Considering that manual analyses may give rise to errors, the CST can perform several analyses, such as time trend analyses, (multiple) regression analyses and scenario analyses. Each model is tested for whether it improves prediction beyond the trend only, and hypotheses are tested for determining the significance of results (Figure B3.15).

FIGURE B3.12
The five modules of the Mars Crop Yield Forecasting System (MCYFS)

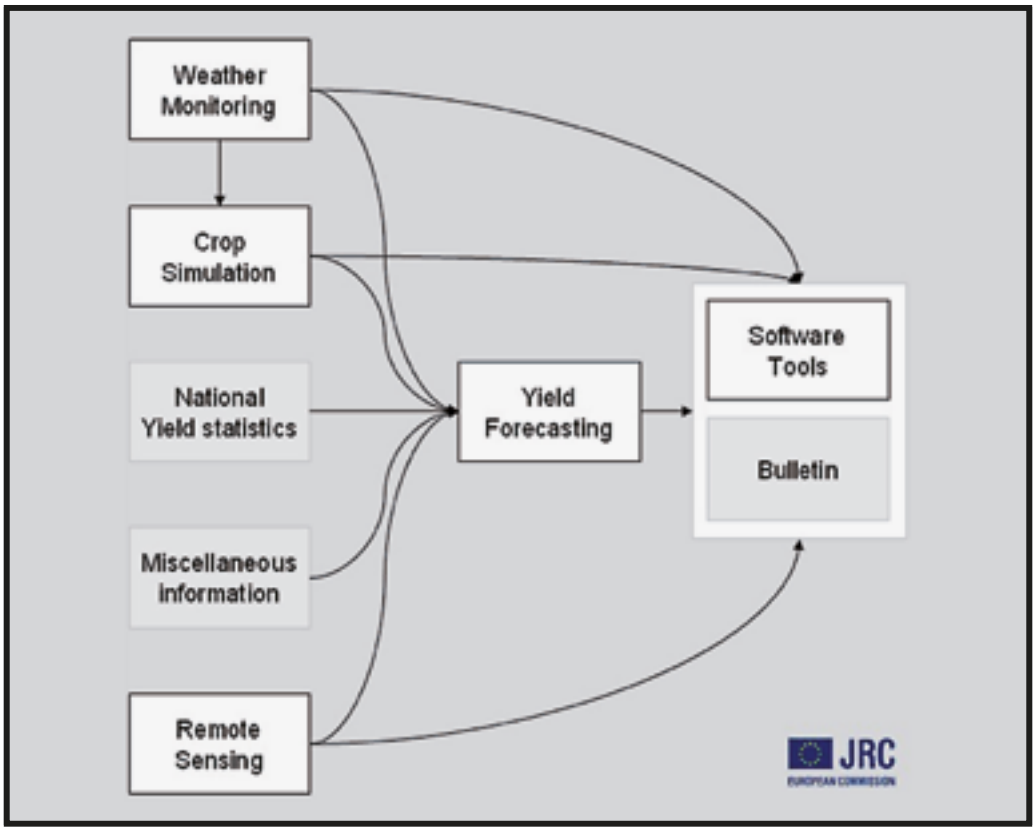


FIGURE B3.13
MCYFS: synthetic schema

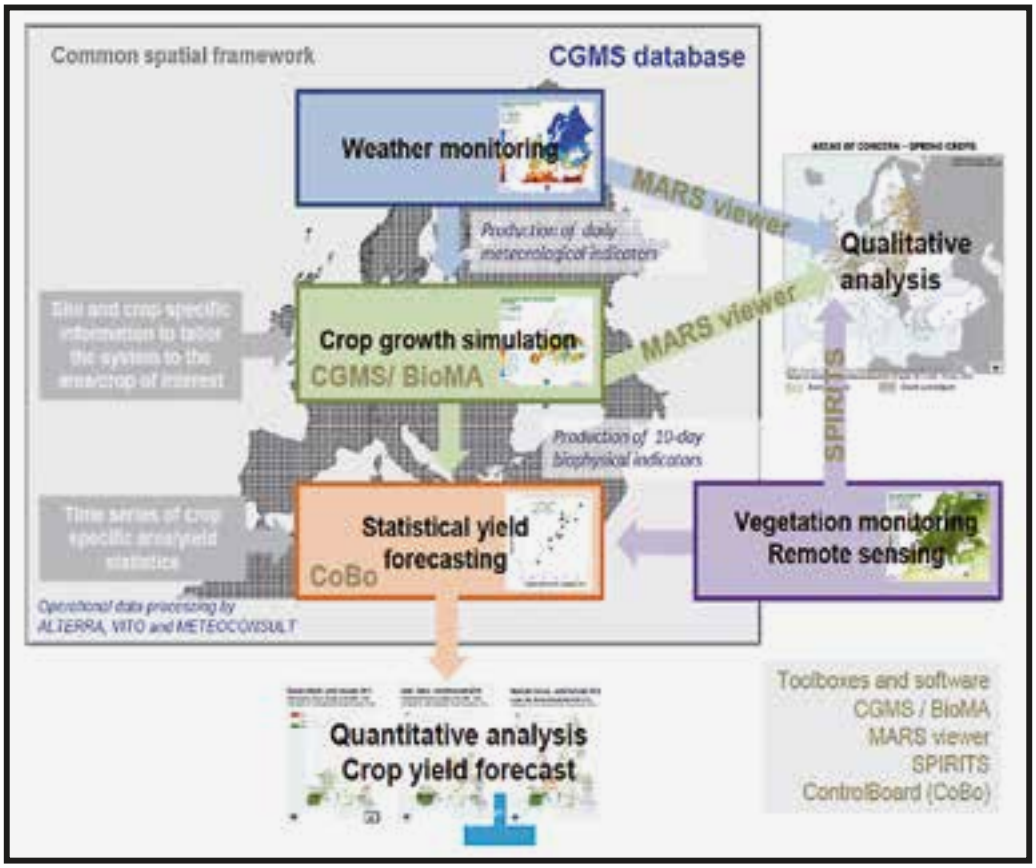
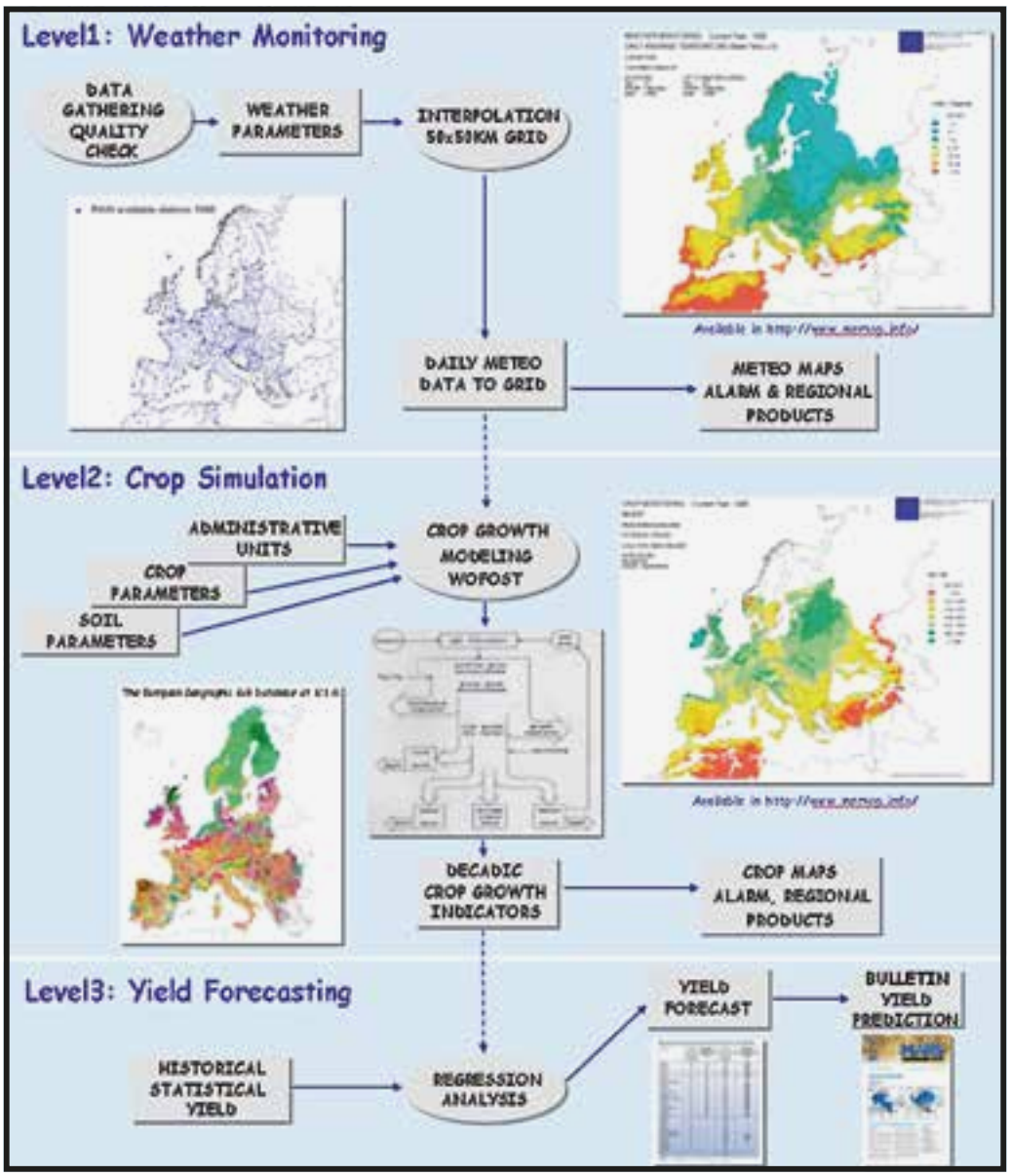
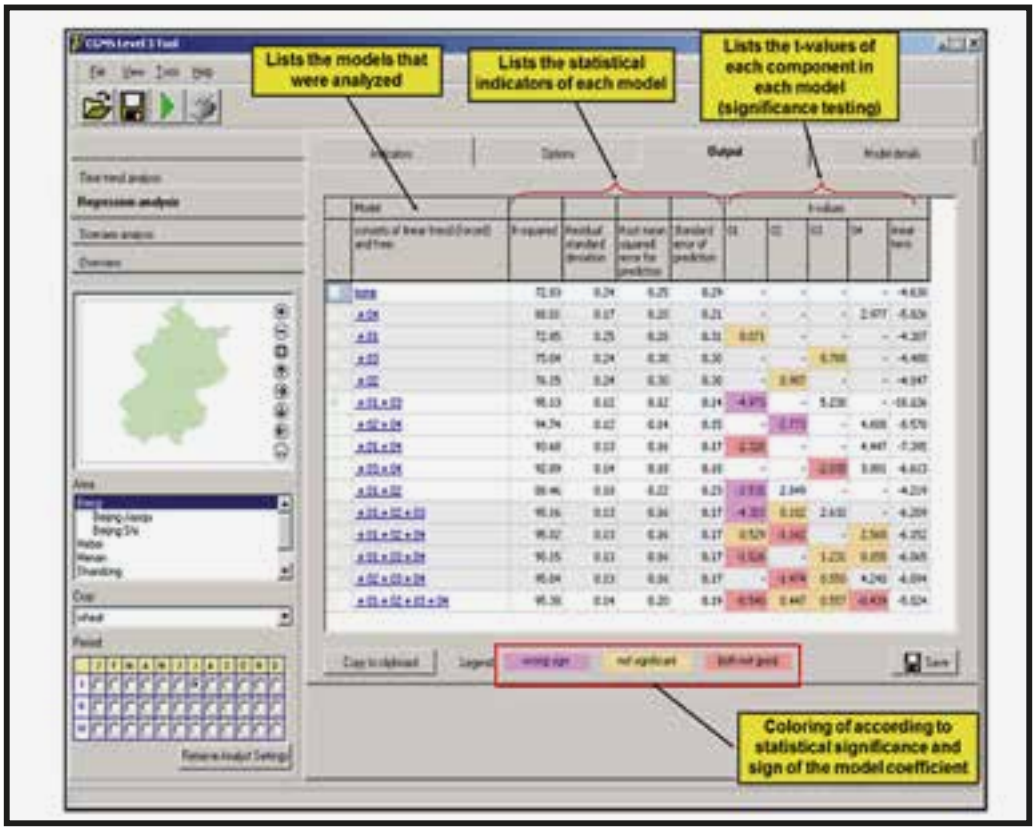


FIGURE B3.14
Descriptive schema of the three operational levels of the MCYFS



Source: http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/Crop-Growth-Monitoring-System-CGMS

FIGURE B3.15
The CGMS Statistical Toolbox (CST)



Source: http://www.e-agri.info/pdf/D62.1_CST_Piloting_workshop.pdf

Annex B3.3 – Websites

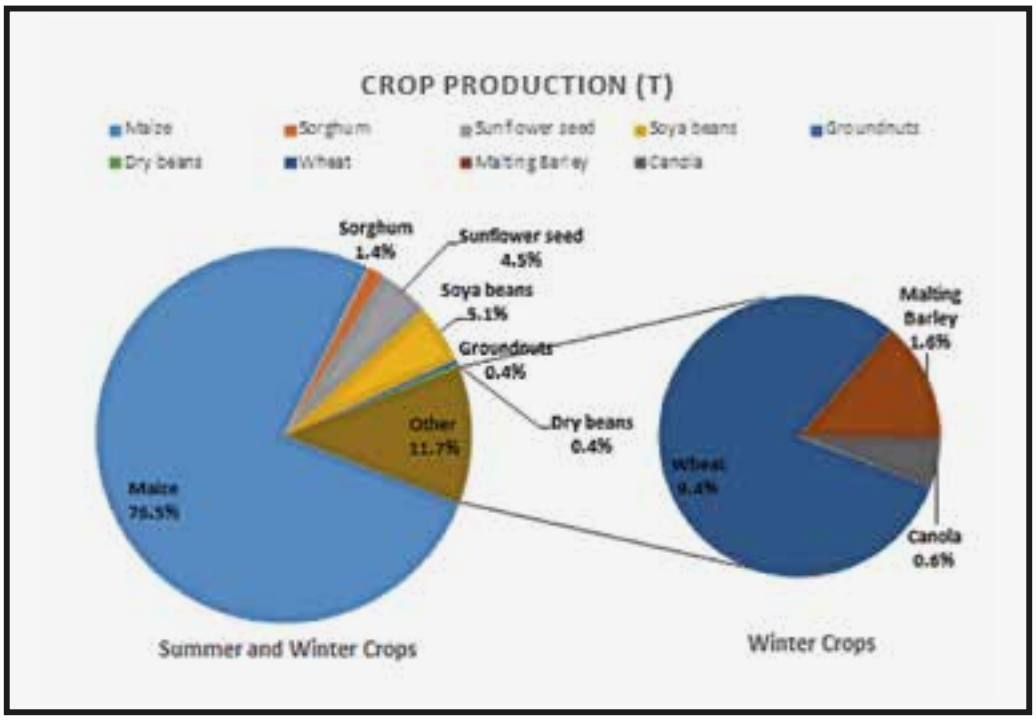
Country	National Institutions	Link
Morocco	CGMS-Maroc	http://www.cgms-maroc.ma/
	Web Mapping	http://www.cgms-maroc.ma/cgms-map/
	Institut National de la Recherche Agronomique (INRA)	http://www.inra.org.ma/accueil1.asp?codelangue=23&po=2
	Direction de la Stratégie et des Statistiques (DSS)	http://www.agriculture.gov.ma/pages/statistiques-agricoles
	Direction de la Météorologie Nationale (DMN)	http://www.marocmeteo.ma/
	Géoportail (Ministère de l'Agriculture)	http://geoportail.agriculture.gov.ma/geoportal/catalog/main/home.page
	Centre Royal de Télédétecton Spatiale (CRTS)	http://www.crts.gov.ma/
	Bank Al Maghrib	http://www.bkam.ma/
	Haut-Commissariat au Plan	http://www.hcp.ma/
Name	**Int'l Organization**	**Link**
EU	JRC-Mars Unit	http://mars.jrc.ec.europa.eu
	WikiMCYFS	http://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Main_Page
	CGMS	http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Models-Software-Tools/Crop-Growth-Monitoring-System-CGMS
	E-AGRI	http://www.e-agri.info/
	VITO	http://www.vito-eodata.be/PDF/portal/Application.html#Home
Group on Earth Observations	GEOGLAM	http://www.geoglam-crop-monitor.org/
FAO	FAOSTAT	http://faostat3.fao.org/home/E
	CLIMPAG	http://www.fao.org/nr/climpag/
WMO	AGMP Agricultural Meteorology Programme	http://www.wmo.int/pages/prog/wcp/agm/agmp_en.php

Annex B4

South Africa

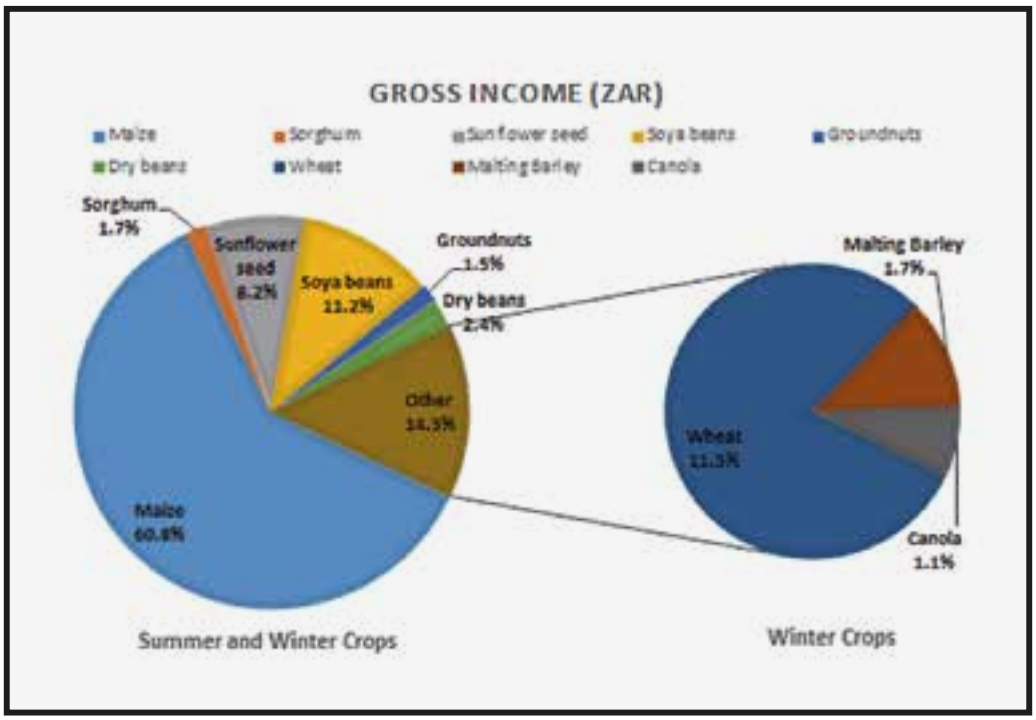
Annex B4.1 – Figures

FIGURE B4.1
Crop production (tons) of summer and winter crops produced in South Africa, including commercial and non-commercial production



Source: DAFF, 2013

FIGURE B4.2
Gross income (South African Rand) of summer and winter crops produced in South Africa, including commercial and non-commercial production



Source: DAFF, 2013.

Annex B4.2 - CEC crop reporting dates against crop calendar

CROPS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Summer Crops												
Maize (East)	PAP (Provincial)	FCE 1st PF RAP	2nd PF	3rd PF	4th PF	5th PF	6th PF	7th PF	FPE	ITP		
Maize (West)	PAP (Provincial)	FCE 1st PF RAP	2nd PF	3rd PF	4th PF	5th PF	6th PF	7th PF	FPE	ITP		
Sunflower seed	PAP (National)	FCE 1st PF RAP	2nd PF	3rd PF	4th PF	5th PF	6th PF	7th PF	FPE	ITP		
Soya beans	PAP (National)	FCE 1st PF RAP	2nd PF	3rd PF	4th PF	5th PF	6th PF	7th PF	FPE	ITP		
Groundnuts	PAP (National)	FCE 1st PF RAP	2nd PF	3rd PF	4th PF	5th PF	6th PF	7th PF	FPE	ITP		
Sorghum	PAP (National)	FCE 1st PF RAP F	2nd PF	3rd PF	4th PF	5th PF	6th PF	7th PF	FPE	ITP		
Dry beans	PAP (National)	FCE 1st PF RAP	2nd PF	3rd PF	4th PF	5th PF	6th PF	7th PF	FPE	ITP		
Winter Crops												
Wheat (Winter)	6th PF	7th PF		ITP	FCE		PAP	1st PF RAP	2nd PF	3rd PF	4th PF	5th PF
Wheat (Spring)	6th PF	7th PF		ITP	FCE		PAP	1st PF RAP	2nd PF	3rd PF	4th PF	5th PF
Malting Barley	6th PF	7th PF		ITP	FCE		PAP	1st PF RAP	2nd PF	3rd PF	4th PF	5th PF
Canola	6th PF	7th PF		ITP	FCE		PAP	1st PF RAP	2nd PF	3rd PF	4th PF	5th PF

Note: Green (▬) indicates the planting season for a specific crop; brown (▬) stands for the harvesting season in South Africa. The Eastern Areas refer to Mpumalanga, Eastern KwaZulu-Nata and South-Eastern Limpopo; the Western Areas refer to Northern Cape, Free State, Gauteng, North West, Eastern Cape, Western Cape, Western KwaZulu-Natal and Western Limpopo. The text represents the official releases of the CEC using the following abbreviations: PF – Production Forecast; FPE – Final Production Estimate; FCE – Final Crop Estimate; PAP – Preliminary Area-Planted; RAP – Revised Area-Planted; ITP – IntentionsTo Plant. All data is released at the end of the month except for the FAE, which is released at the beginning of the month.

Annex B4.3 - Example of SAGIS publication dates

SAGIS

PUBLICATION DATES

	2015											
Monthly Info:	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
SAGIS Monthly Data	26	24	24	28	25	26	24	25	28	26	24	22
Crop Estimates Committee	27	13 & 26	25	29	7 & 26	30	28	26	29	27	25	15
Supply & Demand Estimates Committee												

Weekly Info:	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
SAGIS Weekly Bulletin				2			2			1		3
	8	5	5	9	7	4	9	6	3	8	5	10
	15	12	12	16	14	11	16	13	10	15	12	X
	22	19	19	23	21	18	23	20	17	22	19	X
	29	26	26	30	28	25	30	27	25	29	26	X
SAGIS Weekly Imports & Exports Data			3			2			1			1
	7	3	10	8	5	9	7	4	8	6	3	8
	13	10	17	14	12	17	14	12	15	13	10	X
	20	17	24	21	19	23	21	18	22	20	17	X
	27	24	31	29	26	30	28	25	29	27	24	X
SAGIS Weekly Producer Deliveries Data				1			1		2			2
	8	4	4	9	6	3	8	5	9	7	4	9
	14	11	11	15	13	10	15	13	16	14	11	X
	21	18	18	22	20	18	22	19	23	21	18	X
	28	25	25	30	27	24	29	26	30	28	25	X

Notes:
All publications are released after 12:00 pm on the scheduled date.
X = There is no publication that week.

Annex B4.4. Concepts and definitions used by the CEC

I Annual and perennial crops

1. **Annual crops** are those that are planted and harvested during the same production season.
2. **Perennial crops** need not be replanted after each harvest.

II Annual crops: definition, classification and specific recommendations

1. **Grains**

   Grains refer to the harvested produce of cereals, pulses and oil-bearing crops, excluding crops harvested or used green for forage, silage and grazing and in the case of maize harvested green, also for food.

2. **Cereals (e.g. white maize, yellow maize, sorghum, wheat, barley and oats)**

   2.1 General

   Cereals are annual plants, generally of the gramineous family, which yield grains used for food, feed, seed and industrial purposes. It is recommended that the definition of "cereals" be limited to crops harvested for **dry grain** only, therefore excluding *crops harvested or used green for forage, silage, grazing, etc; and, in the case of maize harvested green, also for food.*

   2.2 Definition

   Cereals are defined as annual plants of the gramineous family which yield dry grains used for food, feed, seed and industrial purposes.

3. **Pulses (e.g. dry beans)**

   3.1 General

   Pulses are annual leguminous plants yielding seeds used for food, feed and seed purposes. In addition to their value as food and feed, pulses are also important in cropping systems for their ability to produce nitrogen and therefore increase soil fertility. The definition "pulses" should be limited to crops harvested for **dry seeds** only.

   3.2 Definition

   Pulses are defined as annual plants of the leguminous family yielding dry seeds used for food, feed, seed and industrial purposes.

4. **Oilseeds (e.g. sunflower seed, soybeans, groundnuts and canola)**

   4.1 General

   Oil crops are annual plants whose seeds or fruit are used mainly for extraction of culinary and industrial oils. The definition of "oilseeds" should be limited to crops harvested for **dry seeds** only, **excluding** crops *harvested green and used for food or feed, or used for grazing and green manure*. The production of oilseeds should always relate to the quantities actually harvested, irrespective of their use after harvest.

4.2 Definition

Oilseeds are defined as dry seeds harvested from annual oil-bearing crops used for food, feed, seed or industrial purposes.

III Additional definitions:

1. Farming unit (farm/farming operation)

1.1 General

A farming unit consists of one or more farms, holdings or pieces of land (whether adjacent or not), operated as a single unit and situated within the same magisterial district/province. A farming unit is a unit on which cultivation is carried out for both commercial and non-commercial purposes, in the open air or under cover (Agricultural survey 1996).

1.2 Definition

A farming unit consists of one or more farms, holdings or areas of land (whether adjacent or not), farmed on as a single unit and situated within the same province. It includes land rented from others, the farmstead and other buildings, cropland, pasture, veld, wasteland and dams, and excludes land leased to others.

2. Commercial farmer

2.1 General

The commercial farmer earns an ongoing and primary revenue from his/her farming business, which forms the major source of income for the family. He/she has access to the technical, financial and managerial instruments necessary to utilize the global market potential.

2.2 Definition

A commercial farmer is a person who produces agricultural products intended for the market.

3. Non-Commercial farmer

3.1 General

The Non-commercial farmer earns very little from his/her farming activities. The crops/livestock generated from the farming activities are merely for home consumption. The surpluses brought to the market constitute a small percentage and usually generate very low incomes. Non-commercial farmers are alienated from the market due to technical, financial and managerial barriers. The family must look for other non-farming ways to generate income. Eventually, the Non-commercial farmer will earn more from the non-farming activities and leave the farming business.

This is a farming operation in which output is produced primarily for consumption

by the farmer and his/her family members, and not for cash sale.

Non-commercial agriculture is a form of agriculture in which almost all of the produce goes to feed and support the household and is not for sale. Some of the output may be bartered. If there is no market trade in any surplus, the economy is classed as tribal; if some of the surplus is sold for necessities (such as salt) the economy is classed as 'peasant'. Very few of the former Non-commercial-type economies remain.

3.2 Definition

A Non-commercial farmer is a person who produces crops primarily for own consumption.

4. Crop area

4.1 Area planted to grain

4.1.1 General

The area planted for grain is defined as the part of the total seeded area that is planted with the intention of harvesting it for grain. Therefore, areas planted with the intention of using grain for silage, grazing, fodder etc. are excluded.

4.1.2 Definition

Area planted for grain is defined as the total number of hectares that are actually planted to a specific crop in a specific production season with the intention of harvesting it for grain.

4.2 Area harvested for grain

4.2.1 General

The area harvested is defined as the area that will be harvested for grain. It is therefore necessary to concentrate on the actual harvested crop area, rather than on the area planted.

This includes all fields harvested for dry grain (whole grain, seed, beans or unshelled nuts) for commercial purposes, or to be retained on farm for seed, animal feed or human consumption. It therefore excludes areas planted but not harvested owing to hail damage or grazing, etc. and areas harvested although not used for grain, but for silage etc.

The term includes areas harvested for dry grain (whole grain, seed, beans or unshelled nuts) for commercial purposes, or to be retained on farm for seed, animal feed or human consumption.

4.2.2 Definition

Area harvested for grain is defined as the total number of hectares of a specific crop in a specific production season that is actually harvested for grain.

5. Grain production

5.1 General

The term refers to grain actually removed from the field.

Some countries obtain estimates of crop production by multiplying the average yield per unit area by the corresponding crop area planted or harvested.

Other countries estimate production on the basis of information collected from various sources, including declarations of producers, deliveries to marketing boards and administrative records. In the first instance, production figures are derived from yield and area, while in the second instance, yields are derived from production and area figures. This excludes harvesting losses and production not harvested for various reasons, e.g. hail damage, crop failure, etc.

5.2 Definition

5.2.1 Total grain production

Total grain production refers to the grain harvested. This includes marketed production and retention on farms.

5.2.2 Marketed production/deliveries

Marketed grain production is harvested grain that is delivered to the market.

5.2.3 Retention on farms

Retention on farms is harvested grain that is retained by commercial farmers for their own purposes, gristing excluded.

Note: Crops delivered for gristing are not regarded as crops retained on the farm, because the first point of delivery is a cooperative, a miller or a trader.

6. Yield

6.1 Definition

Yield is the harvested grain mass per unit area.

6.2 Yield per area planted vs yield per area harvested

Yield per area planted is obtained from the area planted for grain to obtain the production of grain for the specific crop.

Yield per area harvested is obtained from the area that is actually harvested for grain.

6.3 Subjective yield survey vs Objective yield survey

Subjective yield surveys are based on information obtained from farmers or decision makers concerning their fields, on the basis of expert opinions or experience.

Objective yield surveys are based on actual counts and measurements made in a field.

7. Irrigation

7.1 Definition

Irrigation is any fully or supplementarily artificial watering of land for crop production.

8. Crop forecast

8.1 Definition

A crop forecast is a quantitative approximation of the crop size prepared and released before harvest.

9. Crop estimate

9.1 Definition

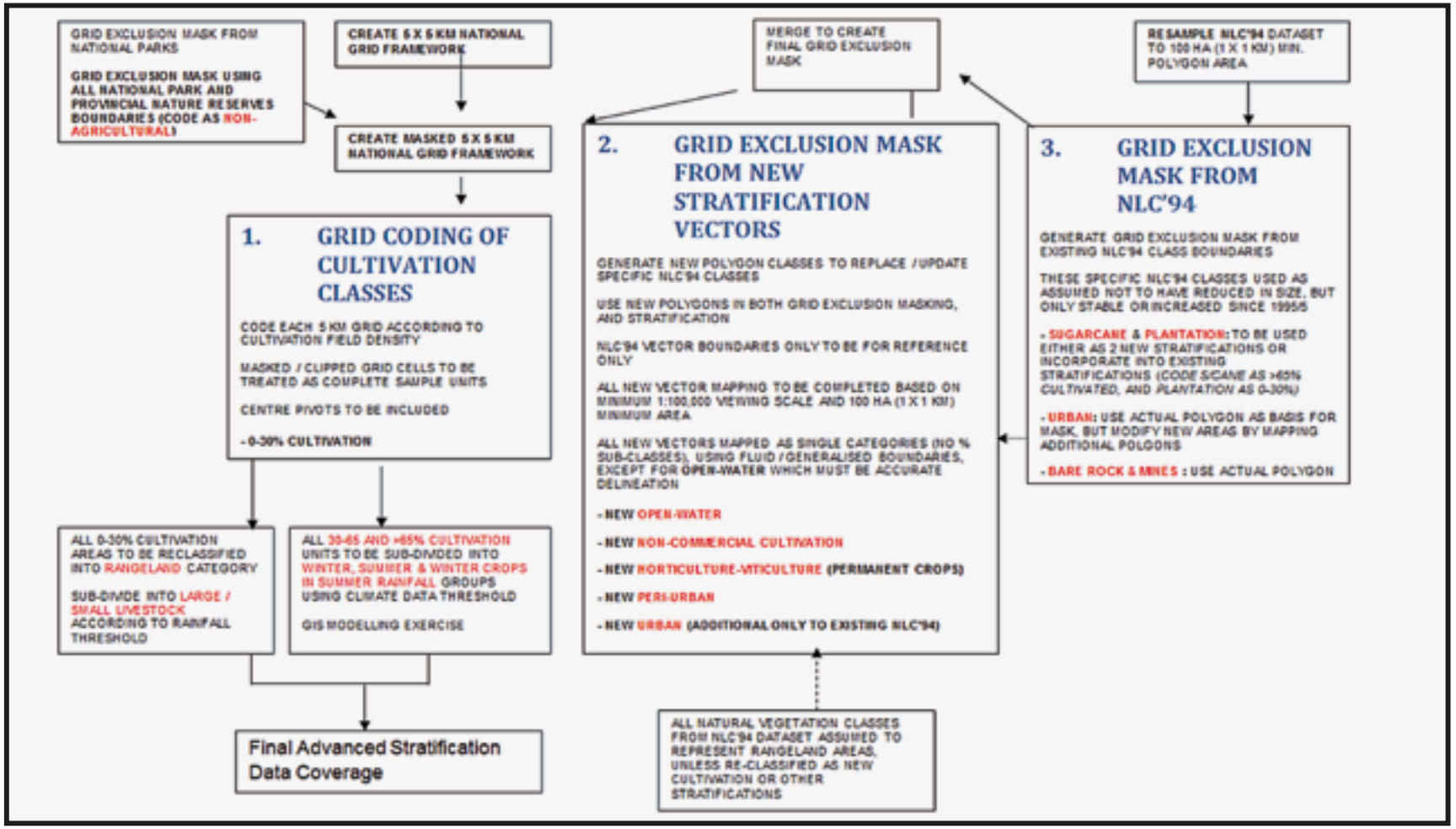
A crop estimate is a quantitative determination of crop size after harvest.

10. Genetically Modified Organisms (GMOs)

10.1 Definition

"'[G]enetically modified organism' means an organism the genes or genetic material of which has been modified in a way that does not occur naturally through mating or natural recombination or both, and 'genetic modification' shall have a corresponding meaning" (GMO Act No. 15 of 1997, Section 1(xiii)).

Annex B4.5 - Advanced Sample Framework Procedure for South African Agricultural Statistics



Annex B4.6 – Websites

Country	National Institutions	Link
South Africa	NAMC	http://www.namc.co.za/
	CEC	http://www.daff.gov.za/daffweb3/home/crop-estimates
	DAFF	http://www.daff.gov.za/
	ISCW	http://www.arc.agric.za/arc-iscw/Pages/ARC-ISCW-Homepage.aspx.
	GCI	http://www.arc.agric.za/arc-gci/Pages/ARC-GCI-Homepage.aspx
	SGI	http://www.arc.agric.za/arc-sgi/Pages/ARC-SGI-Homepage.aspx
Name	**Int'l Organization**	**Link**
Group on Earth Observations	GEOGLAM	http://www.geoglam-crop-monitor.org/
	USDA-FASS	http://www.fas.usda.gov/
USA	USDA-NASS	http://www.nass.usda.gov/

Annex B5

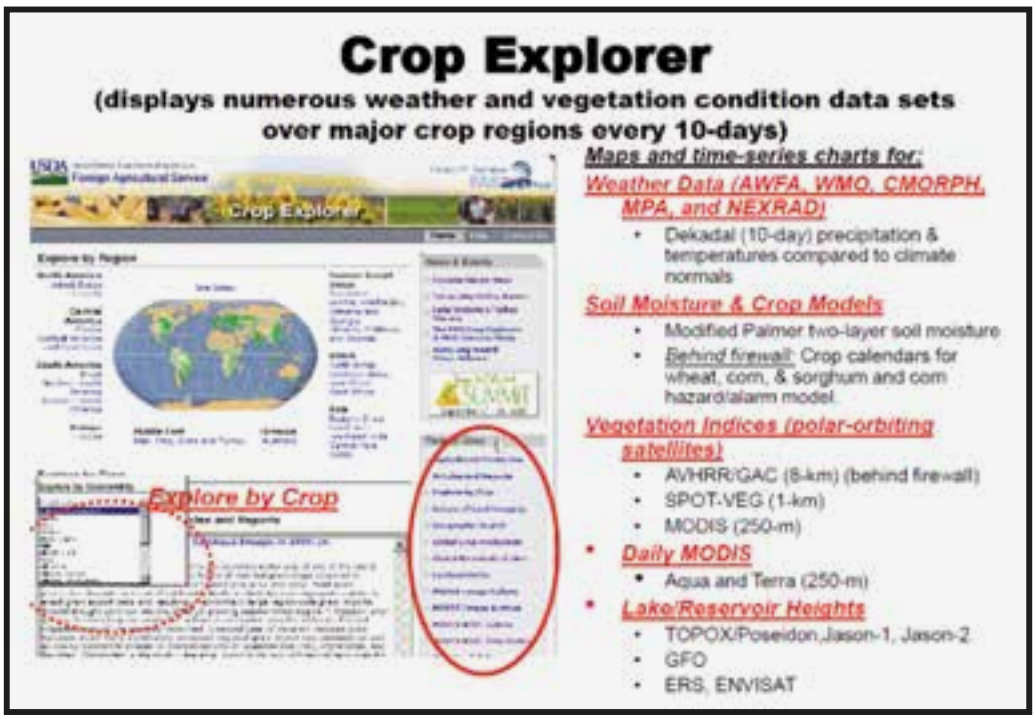
USA

Annex B5.1. Figures

FIGURE B5.1
FAS's overseas activities, with attachés in 75 posts

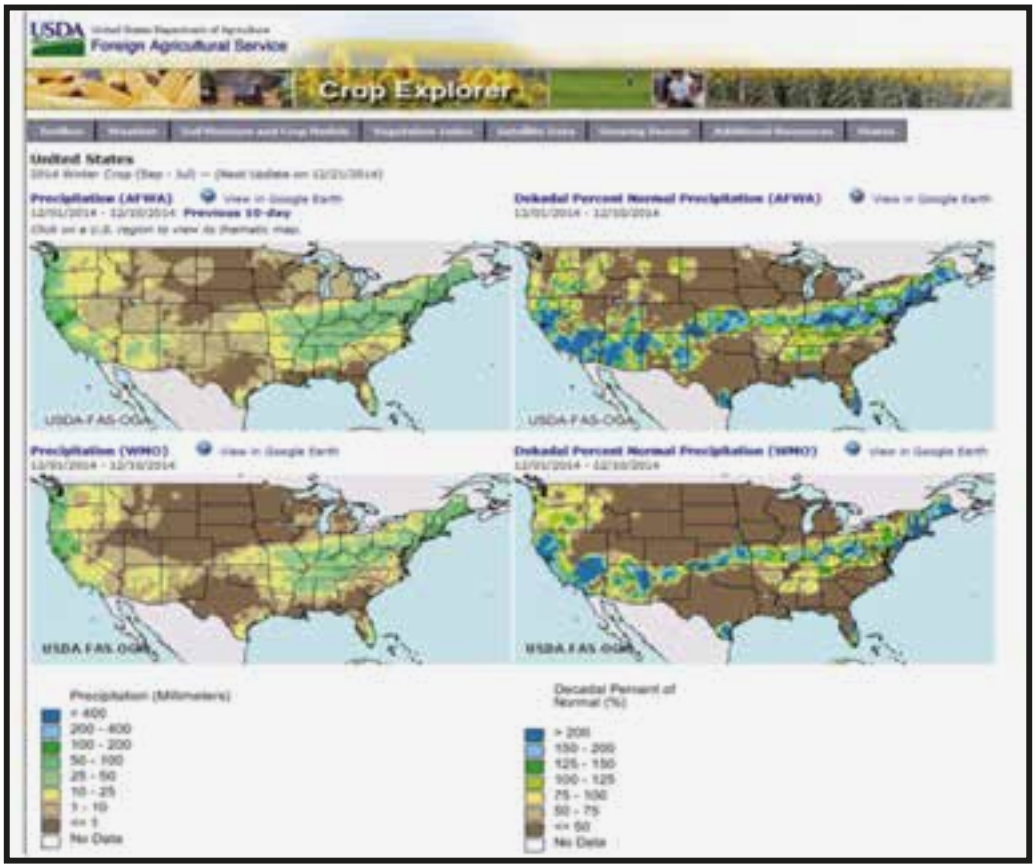
Source: Reynolds, 2013

FIGURE B5.2
USDA-FAS-PECAD: Crop Explorer



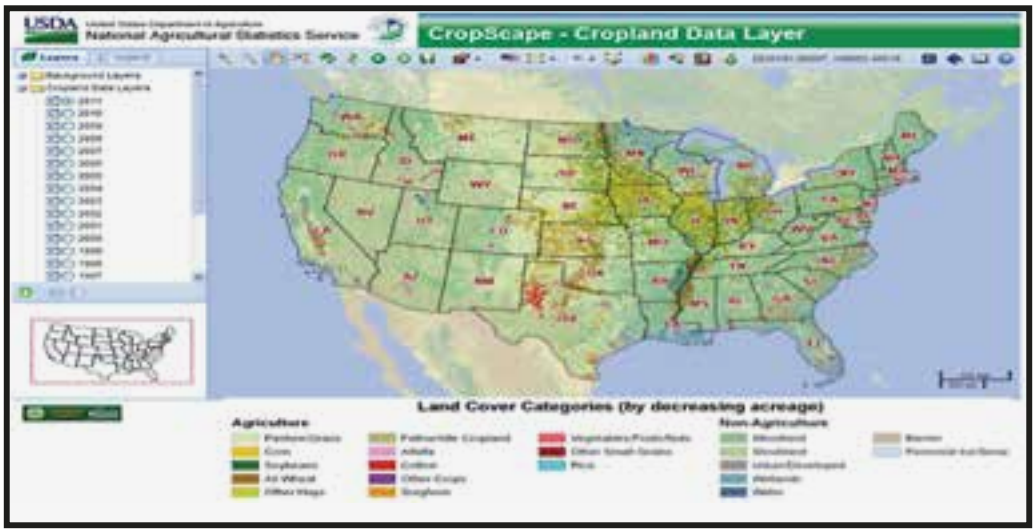
Source: Reynolds, 2013.

FIGURE B5.2A
USDA-FAS-PECAD: Crop Explorer



Source: http://www.pecad.fas.usda.gov/cropexplorer/Default.aspx

FIGURE B5.3
CropScape: Cropland Data Layer



Source: http://nassgeodata.gmu.edu/CropScape/

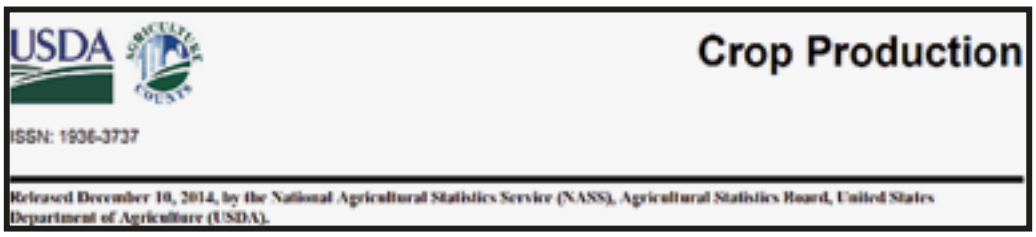
FIGURE B5.3A
CropScape: Cropland Data Layer

Source: http://nassgeodata.gmu.edu/CropScape/.

FIGURE B5.4
VegScape: Vegetation Condition Explorer

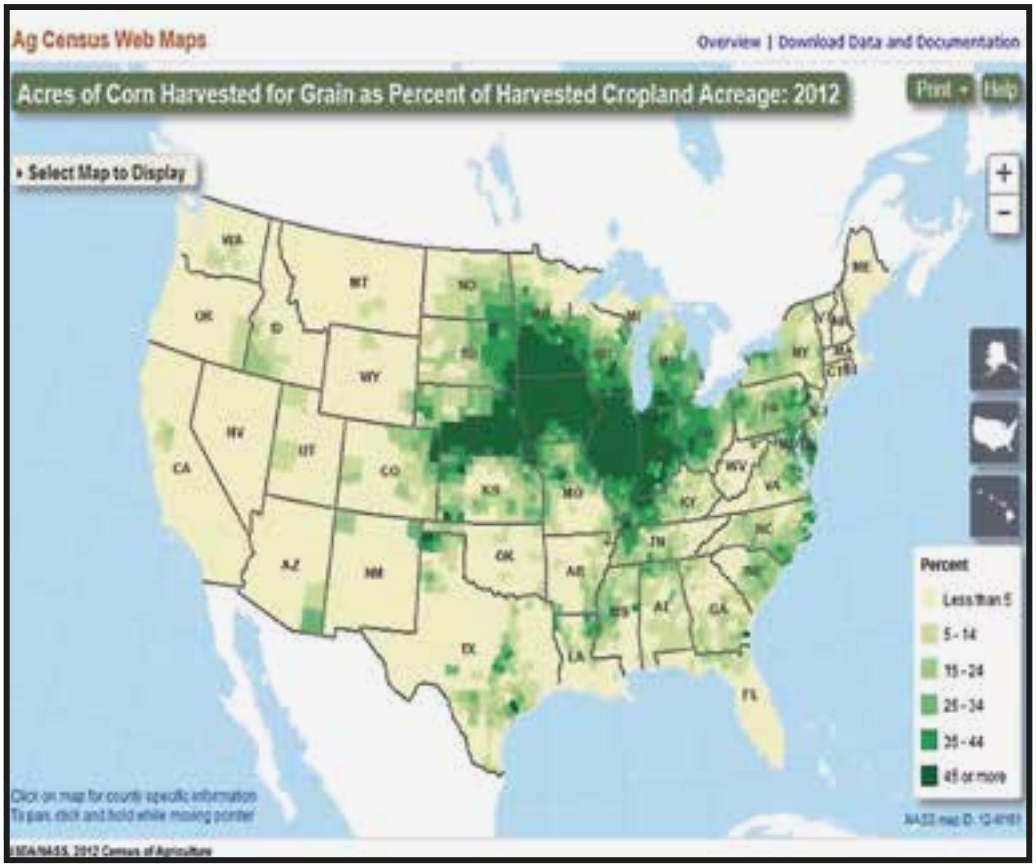
Source: http://nassgeodata.gmu.edu/VegScape/.

FIGURE B5.5
Monthly Crop Production Report



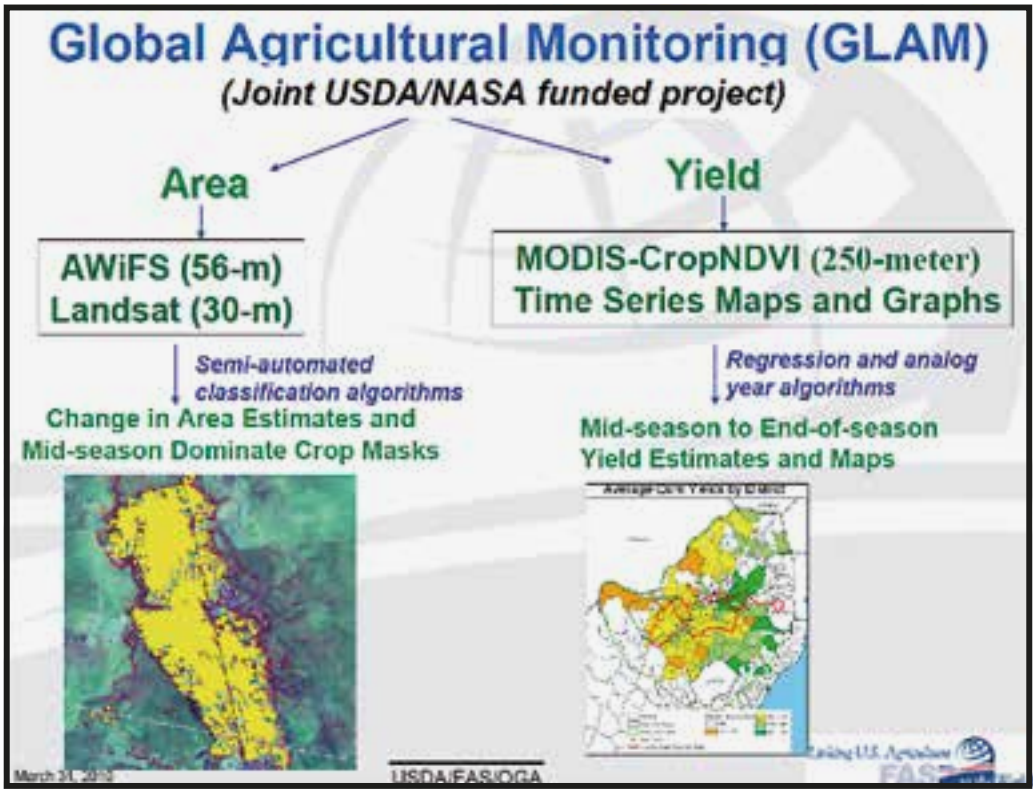
Source: http://usda.mannlib.cornell.edu/usda/nass/CropProd//2010s/2014/CropProd-12-10-2014.pdf

FIGURE B5.6
US Census of Agriculture (Acres of Corn Harvested for Grain as Percentage of Harvested Cropland Acreage: 2012).



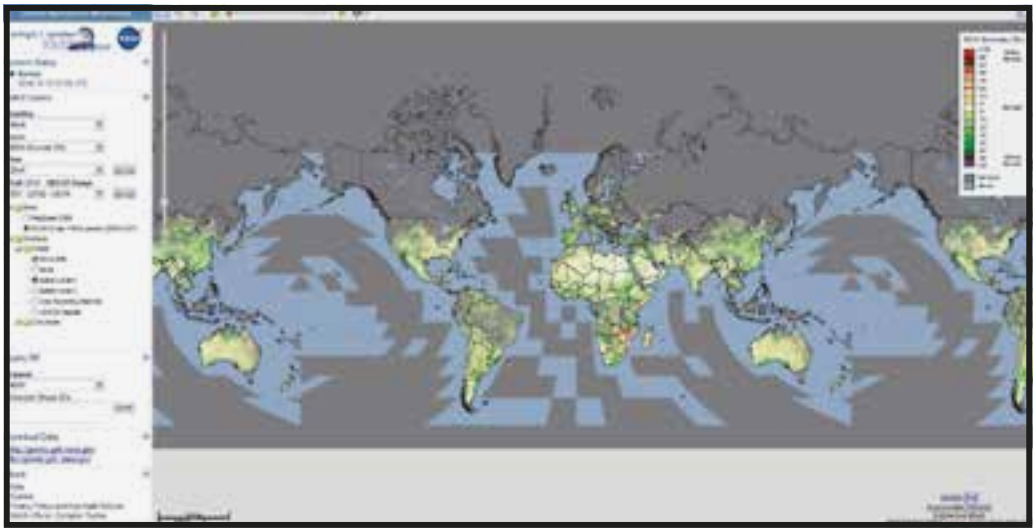
Source: http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Maps/

FIGURE B5.7
Global Agricultural Monitoring (GLAM)



Source: from Reynolds 2010

FIGURE B5.8
Web application for GLAM



Source: http://glam1.gsfc.nasa.gov/

Annex B5.2. Websites

Country	National Institutions	Link
USA	USDA-NASS	http://www.nass.usda.gov/
	USDA-CropExplorer	http://www.pecad.fas.usda.gov/cropexplorer/
	USDA-CropScape	http://nassgeodata.gmu.edu/CropScape/
	USDA-VegScape	http://nassgeodata.gmu.edu/VegScape/
	USDA-Ag Census Web Maps (2012)	http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Maps/
Name	**Int'l Organization**	**Link**
Group on Earth Observations	GEOGLAM	http://www.geoglam-crop-monitor.org/
FAO	FAOSTAT	http://faostat3.fao.org/home/E
	CLIMPAG	http://www.fao.org/nr/climpag/
WMO	AGMP - Agricultural Meteorology Programme	http://www.wmo.int/pages/prog/wcp/agm/agmp_en.php

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