# IMPROVING THE USE OF GPS, GIS AND RS FOR SETTING UP A MASTER SAMPLING FRAME

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July 2013

## Summary

In this report, the application of GIS, GNSS and Remote Sensing in sampling frames construction have been reviewed. In a first step, information on different area frames developed throughout the world has been compiled, with particular emphasis on the use of these technologies for construction, maintenance and management of geographical information. It is observed that the use of satellite images and GIS is widespread for these purposes. GPS technology is introduced slowly especially in the field work. . Some African countries are particularly active in the introduction of GIS, GPS and RS in setting up Master Sampling Frames, particularly Ethiopia

In a second step, different authors proposals on the three mentioned technologies for sampling frames studies have been analyzed. Remote sensing has a long history of use and its main applications have been: territory stratification, optimization of sampling design (definition of the size of the sampling unit, sampling scheme and sampling stages) and improved estimates. Therefore the GIS as GNSS have extensive application in information management from the sampling frames. The ability of mobile GIS systems over PDAs for data collection, geolocation and measurement of surfaces, opens an important area for improvement. Finally some proposals of future research have been formulated.

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## 1. Introduction.

The Action Plan of Global Strategy to Improve Agricultural and Rural Statistics for Food Securiry, Sustainable Agriculture and Rural Development [1], sustains in the following foundations:

1. Establishment of a basic statistical dataset from agricultural and rural information systems, both current and future.
2. Integration of agricultural statistics in National Statistics Systems.
3. Promote the sustainability of Agricultural Statistics Systems, by means of governability and strengthening of the statistical capacity.

Concerning the second idea, the Global Strategy has defined an especial action plan. It is established as priority the integration of the Official Systems of Agricultural Statistics in the National Statistics Systems. Traditionally, Agricultural Ministries are in charge of executing the official agricultural statistics in a totally independent manner regarding the national organisms in charge of executing the whole statistical operations, and not existing in many cases coordination between both organizations and even notable differences. On the other hand, the capture of agricultural information is usually based in very heterogeneous features units such as farm (economic unit), household or family (economic unit) and everything related to portion of land (ecological unit). Therefore it is essential to integrate agricultural statistics in the National Statistics Systems.

Among the many actions to reach this objective, the use of Master Sampling Frame is proposed.

A **SAMPLING FRAME** can be defined as "the *set of source materials from which the sample is selected"* [2]. Hence the frame must be useful to delimitate, identify, and ease access to the elements of the population to be sampled. The frame must also include useful auxiliary information for the design of the sample selection procedure and/or in the process of estimation [3] [4]. The sampling frames of frequent use are list frames, area frames, and mixed frames.

The desired properties of a sampling frame are [2]:

1. To have completeness, meaning that all the elements of the population are covered.
2. To have accuracy, meaning that every element of the population is included once and only once.
3. To be a current frame, thus it should be up to date.

The sampling frame must provide the necessary means to identify unequivocally every sampling unit and its elements should be ordered in a way that the random selection of the sample can be carried out in an efficient way [4].

An area frame is a partition or segmentation of the territory where a population is located, in sampling units (segments) [4], meanwhile a list frame is made up of a list of the individuals of the target population [2].

A **MASTER SAMPLING FRAME** is *used to select samples either for multiple surveys, each with different content, or for use in different rounds of a continuing or periodic survey* [2]. *A master sampling frame is a sampling frame that provides the basis for all data collections based on sample surveys and censuses in a certain sector* [5].

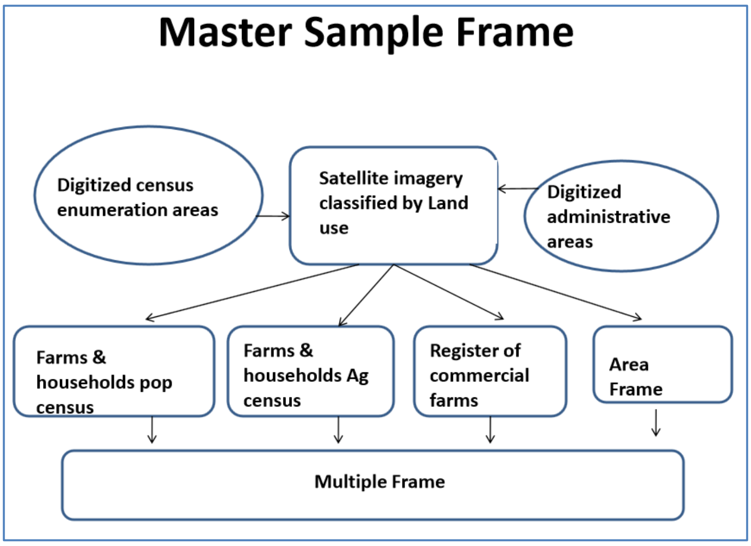
For sampling frame becomes a master sampling frame in the rural sector, Vogel [6] proposes that it shoud be constructed in such a way that:

- Becomes survey basis for data collections for agricultural statistics for all providers in the National Statistical System
- Provides ways to connect households, farms, and land
- Is made available to all institutions in National Statistical System for data collection

Vogel [6] suggest tan Master Sampling Frame can be constructed using the following procedures:

1. Land classification using remote sensing
2. Geo-reference boundaries of Administrative areas
3. Geo-reference census enumeration areas
4. Sample frames for farms, households, land
5. Combine into multiple frames, if needed

Vogel's proposal can be sown in the following figure [6].




Source [6].

As seen in the figure, for the construction of a master sampling frame is indispensable to have properly identified over the territory the location of the different constituent elements, this implies the necessary georeference of all of its elements. Therefore is necessary to use current geomatic tools for the construction of the frame: Digital Cartography, Satellite Images and Remote Sensing, Geographic Information Systems, and Global Navigation Satellite Systems (GPS, GLONASS, Compass, Galileo).

# 2. Definitions.

## 2.1. Remote Sensing (RS).

According to American Society of Photogrammetry, **REMOTE SENSING** imagery is acquired with a sensor other than (or in addition to) a conventional camera through which a scene is recorded, such as by electronic scanning, using radiations outside the normal visual range of the sensor and camera—microwave, radar, thermal, infrared, ultraviolet, as well as multispectral, special techniques are applied to process and interpret remote sensing imagery for the purpose of producing conventional maps, thematic maps, resources surveys, etc., in the fields of agriculture, archaeology, forestry, geography, geology, and others [7].

The purpose of using remote sensing for the construction of Master Sampling Frames, is to obtain conventional cartography and thematic maps (land use) that help on one side to perform the initial territory stratification, as well as to provide geographic information that will allow delimitate the sampling units, design optimization and improve estimates. The satellite images can also be especially useful for preparing the necessary material for the field work.

## 2.2. Geographic Information Systems.

**GEOGRAPHIC INFORMATION SYSTEM "GIS"** is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose. These tools are used to manipulate, and operate on standard geographical primitives such as points, lines and areas, and/or continuously varying surfaces known as fields [8].

It can be noticed that the operations related to the construction of a master sampling frame can be done in a Geographic Information System. Thus, it is a main tool for the implementation of a sampling frame, even more given the possibility to manage databases, even ungeoreferenced data. It can be a tool of especial utility for the integration of area frames, list frames and mixed frames.

The construction of a master sampling frame inside a GIS is very useful for the subsequent process of sample selecting, material preparation and field data collection, for the capture and handling of the information, and for the later treatment and analysis of it. Been able to rely with all the information in an integrated digital support, could be very advantageous for its use in portable devices (notebook, tablet, GPS receivers) in the field information capture process, which will allow a notable reduction in time and costs of data gathering and processing.

### 2.3. Global Navigation Satellite Systems.

GNSS is a system consisting network of navigation satellites monitored and controlled by ground stations on the earth, which continuously transmit radio signals that are captured by the receivers to process, and thus to make it possible to precisely geolocation of the receiver by measuring distances from the satellites and to provide precise time information any were in the world at any time [9]. A Global Navigation Satellite System allows users receivers provided to determine their position ( longitude, latitude, and elevation) on the Earth's surface.

Currently, there are many GNSS systems available and in use (the American system GPS – Global Positioning System – and the Russian system GLONNAS – Globanaya navigatsionnaya sputnikovaya sistema-) or in development (the Chinese system BDS – BeiDou Navigation Satellite System, also known as COMPASS and the European Union system GALILEO).

The use of GNSS equipment for the construction of a master sampling frame becomes necessary from the moment it is needed to geolocate and digitalize some of the elements that compose the frame. On the other hand, GNSS systems can be especially useful in the field data collection process because the navigation utilities allow the surveyor guidance to precise positions where the data has to be acquired.

## 3. Operational Area Frames.

In the meeting celebrated in Rome on December 3-5 of 2012, concerning Master Sampling Frames (MSF) for Agricultural and Rural Statistics, many frames built in different countries were presented. Information on different area frames built throughout the world has been compiled, with particular emphasis on that aspects of setting up related to the use of satellite images (Remote Sensing), GIS and GPS. The information collected is presented in table 1.

### 3.1. Area Sampling Frames in America.

The construction of area frames for agricultural uses is not recent. Already in the 20th century in the United States of America, the National Agricultural Statistics Service (NASS) has been obtaining statistics based upon this methodology. The USA sampling frames for agriculture [10], are composed by two elements: a frame list where the farmer, the agricultural agents, and parcels, are the sampling unit; and another area frame where the territory is stratified, dividing it in blocks that also divide in segments that are delimited by permanent boundaries. These two frames are integrated into a mixed frame with the purpose of exploit the efficiency advantage of the list frame and that the area frame is complete. The construction of the area frame was done using satellite imagery, digital maps, GIS software, and aerial photography.

This American area frame has served as a methodological basis for the construction of many other frames in the world. In Table 1 is presented a compilation of different area frames built in other countries.

In the American continent, the construction of area frames with agricultural aims is clearly based in the American system; it has a territorial stratification according to soil usage employing either orthophotographs (Guatemala) or satellite imagery (Chile, Colombia, and Peru), and defined segments over permanent boundaries. The most recent area frames created (Chile) or updated (Guatemala) have chosen the segments with geometric boundaries (square). The sampling design based on the area frames are stratified and bietapic probabilistic type.

## 3.2. Area Sampling Frames in Europa.

In Europe the LUCAS system has been selected which is based in the observation of points on the territory. A two-stages sample design was adopted. The primary sampling units (PSUs) are formed by cells of a grid with a size Regular of 18km by 18km, and secondary sampling units (SSUs) are rectangles (1 500 m x 600 m) located in each PSU. Each rectangle contains 10 sampling points. The sample contains approximately 10 000 PSUs, covering the entire territory of the EU. The LUCAS observation is carried out at the exact spots where the SSUs are located [11].

Four countries of the European Union have systems based on specific area frames, different from the LUCAS system. Spain uses a bietapic stratified system (ESYRCE – Encuesta sobre Superficies y Rendimientos de Cultivos en España), where the primary units are square blocks of 10 x 10km and the secondary units are cells of 1 x 1 km. inside every selected cell a 700 x 700 m square is observed located in the SW vertex (segment). The bietapic stratified area frames (based on permanent boundaries) have been built in the under-cover intensive crop zones of Andalusia.

France relies with the TERUTI system. It is a two level system, with a first level of square segments. 36 points separated by 300m are observed inside every square. The observation of the point in the field covers a 3m diameter circumference, in the case of basic observations; and 40 m of diameter in extended observations. This system also has been adopted in Bulgaria which is known as BANCIK. In Italy the POPULUS system is formed by a systematic sample of points that make a grid of 500 x500 m.

## 3.3. Area Sampling Frames in Asia.

Projects to implement area frames have been developed in Asia, in countries such as Philippines, Thailand, and Indonesia. In the 1980's, the Philippines developed a frame based on satellite imagery, orthophotographs, and digital cartography, in the Pangsainan area. Since 2006 it has been developing a project in Isabela, adopting the methodology proposed by the LUCAS system of the European Union. In Indonesia, the area frame is formed by blocks (PSU), which at the same time are constituted by 10 x10 km squares. These blocks were divided in 40 segments (SSUs) of 500 x 500 m. Inside every block four segments were selected, employing a systematic aligned sampling with a distance threshold method.

## 3.4. Area Sampling Frames in Africa.

The projects developed in Africa are of special relevance due to their innovation in the building or updating of sampling frames. In the Kaduna State of Nigeria, the frame developed, in collaboration with the NASS, is formed by a territorial stratification where blocks are built based on permanent boundaries. Points are randomly selected inside the blocks. The field work consists in locating the point with the aid of GPS equipment, and find operator of land under point collecting information from the operator.

Another proposed classic method to be used as a Sampling Frame Creator is cross points of latitude and longitude (Dot Sampling Method) over Google Earth images, as it is done in Tanzania. The system is constituted by a regular point grid directly located on the web site and the observations are done over the images on-screen. The estimations are made from point recounts that have a determined use.

In recent years in Morocco, an update project of area frames which was built in the 80's has been developing. This frame update is based in the territorial stratification employing photo-interpretation on orthorectified XS images Spot 5 and 10m. For this, an application has been developed for the automatic stratus-building works (application SIG pour l'automatisation de la methode "d'échantillonnage a base areolaire), this GIS application generates rectangular PSUs, which are split into in rectangular segments (SSUs), selected with SRS. Additionally, these segments are adjusted to natural borders.

### 3.4.1. Master Sampling Frame for Rural Statistics in Ethiopia.

The Central Statistics Agency of Ethiopia (CSA) is carrying out a Master Sampling Frame building project, where existing frames are integrated to perform agricultural surveys with the frame used for Rural Households Surveys [12]. In the developed work is proposed the integration of the Enumeration Areas (EAs), defined over a cartographic and geo-referenced base during the execution of the population census with land cover classification from satellite imagery. The frame used by the National Integrate Household Survey is a list type formed by the EAs as primary sampling units (PSUs) and the Households as secondary sampling units (SSUs). PSUs are selected with a probability proportional to size (pps) systematic sampling and SSUs are selected with systematic sampling.

The CSA has developed the National Strategy for the Development of Statistics (NSDS). One of its objectives is setting up a master sampling frame for rural areas. This frame integrates existing list frames (list of enumeration areas from population and housing census, list frame for collecting agricultural data, and community list frame) with a new area frame which is expected to result in more timely and accurate data.

The CSA, with the support of the European Union and FAO who have given technical advice, has elaborated a land cover data base which will *"provide a standardized, multipurpose product useful for environmental and agricultural purposes"*. The 5m resolution SPOT imagery was used for territorial stratification, and MAD CAT (Mapping Device and Change analysis tool) software was used for image processing.

A Sampling Frame was carried out having as basis the enumeration areas (EAs) and the land cover map. The territorial stratification was done based on the land use intensity. The EAs (portion of territory that occupies between 150 and 200 households in rural areas) were considered as PSUs; therefore, proceeding to their digitalization and geo-referencing using cartography and GPS field data. The PSUs are selected with a probability proportional to size and then divided in segments of 40 Ha. Two segments were selected out each EAs of the sample. The whole process was performed with informatics support, cartographic base, and digital data bases.

The project development includes, beside the construction of the frame, activities such as: (i) education and training of the personnel involved in any type of activity in the frame construction; (ii) field data production; (iii) usage of Information Technology Systems (GIS and GPS); and (iv) treatment of the obtained field data.

The results obtained from the comparison of the estimations of the proposed system with the estimations of the frame list were validated as part of the final stage of the project.

An important aspect of master sampling frame is the Implementation on GIS and IT supported activities orientated to facilitate data collection, as it is the use of GPS for identifying the segments boundaries, for delineating segments, or for measuring fields within segments.

As shown in table 1, most of the countries studied, satellite images have been used for the construction of area frames, except in Europe where the use of ortho-photographs still has predominance. GIS have been imposed in the management of information in all countries. On the contrary the introduction of GPS technology has occurred only in those projects newly established or which are being updated.

Table 1. Operational Area Frames

| Country | Region | Sampling Frame | Type | Remote Sensing | GIS | GNSS | Ref. |
|---|---|---|---|---|---|---|---|
| American Continent | | | | | | | |
| USA | | List | Farmers, agri-businesses | | | | [10] [13] [14] |
| | | Area | Land use strata / block /segments permanent boundaries | Satellite imagery | GIS software | | |
| | | Mixed | | | | | |
| Brasil | | MSF Household Survey System | Census enumeration Area Frame | | | | [15] |
| | | MSFr Agricultural Surveys | Agricultural Census (list frame) | | | | |
| | | | Area Frame - enumeration Area Frame | | | | |
| | | | List frame x Area frame | | | | |
| Chile | | Mixed | Stratified area frame / stratification by enumeration Area Frame, square segments (500 x 500 m) | Satellite images and orthophotos used for stratification(land use intensity) and for field materials | GIS software used | | [16] |
| Colombia | | Area Frame | Stratified area frame. PSUs and SSU define with permanent boundaries | Satellite images and orthophotos used for stratification(land use intensity) and for field materials | | | [17] [18] [19] |
| Ecuador | | Mixed | Area frame. PSUs (≈10 $km^2$) and SSU (≈2 $km^2$) define with permanent boundaries | | | | [20] [21] |

Table 1. Operational Area Frames

| Country | Region | Sampling Frame | Type | Remote Sensing | GIS | GNSS | Ref. |
|---|---|---|---|---|---|---|---|
| Guatemala | | Mixed | Stratified area frame / block squares (1 x 1 km), segments - dimension function of the strata (50, 25 and 6.5 ha) | Orthophotos images for field materials | GIS software used | Collection of tracks with GPS | [22] |
| Honduras | | Mixed | Stratified sampling, with replicas of segments within each stratum. | | | | [23] |
| Perú | | Mixed | Land use strata / block /segments permanent boundaries | Satellite images used for stratification and for | Cartographic material made from satellite images, orthophotos and vector files (GIS) | | [24] [25] |
| Europe | | | | | | | |
| European Union | | Area Frame -LUCAS | Systematicas area frame sampling in two stages: PSUs that are cells in a regular grid with size 18x18 km and SSUs that are 10 points regular distributed in a rectangular of 1.500 m x 600 m | Most recent ortho-rectified aerial photographs are used (where available) | | GPS used for point localization | [26] [27] [28] [29] |
| Bulgaria | | Area Frame –Bancik | Systematicas area frame sampling in two stages: PSUs that are cells in a regular grid with size 6 x 6 km and SSUs that are 36 points, arranged in a 6x6 point grid, each 300 m | | | | [27] [30] |

Table 1. Operational Area Frames

| Country | Region | Sampling Frame | Type | Remote Sensing | GIS | GNSS | Ref. |
|---|---|---|---|---|---|---|---|
| Francia | | Area –TERUTI LUCAS | Systematicas area frame sampling in two stages: PSUs that are cells in a regular grid with size 6 x 6 km and SSUs that are 36 points, arranged in a 6x6 point grid, each 300 m | | | | [27] [31] |
| Italia | | POPOLUS ( Permanently Observed POints for Land Use Statistics ) | Systematic sample of points on a regular of 500 x 500 m | Interpretation of orthophotos | Software photo-interpretation | | [32] [33] |
| Norway | | Area- AR18X18 | Systematic sampling. Sampling unit of 1 x 1 km. | Aerial photographs | | | [34] |
| Spain | National (ESYRCE) | Area Frame | Spatial systematic sampling square segments (700x700 m). 3 segments selected by block (10 x 10 km). National Topographic Map at 1:50,000 scale | Material using orthophotography | Access planning segments is done using mapping tools based on the Web or GIS systems. | Collection of tracks with GPS | [35] |
| | Andalucía | Area Frame | Stratified area frame / PSUs and SSUs (segments) permanent boundaries PSUs and SSUs (segments) | Photo-interpretation on orthophotography. | Frame building with GIS. Field material and data storage in GIS. | | [4] |

Table 1. Operational Area Frames

| Country | Region | Sampling Frame | Type | Remote Sensing | GIS | GNSS | Ref. |
|---|---|---|---|---|---|---|---|
| Asia | | | | | | | |
| Indonesia | West Java Province | Area Frame | Spatial Systematic Aligned Sampling with a distance threshold. Square segments (500x500 m). 4 segments selected by block (10 x 10 km). | | GIS Arc-View software was employed to extract sample segments | | [36] |
| Iran | Province of Hamadan | Area Frame | Stratified area frame. Segmentes of 500 x 500 m and 700 x 700 m. (sampling rate 0,4 %) | Landsat imagery aerial photography used as base material | | Hand-held GPS used in field work | [37] |
| Philippines | Pangasinan (1980) | Area Frame | Random sample of 72 segm., ≈25 ha. | Landsat imagery aerial photography and topographic maps | | | [38] |
| | Isabela (2006 | Area Frame | Similar LUCAS | Landsat imagery, Google Earth imagery, NAMRIA topographic maps and NSO provincial/ municipality/barangay shape files. | GIS software and shape files | PSUs and SSUs were located using GPS and magnetic compass | |
| Thailand | | Area Frame | Stratified area frame. Two-Stage Sampling. PSUs and define with permanent boundaries. SSU | Satellite images used for stratification(land use intensity) and for field materials | GIS software used | GPS used to prepare the information and locate the segments. | [39] |

Table 1. Operational Area Frames

| Country | Region | Sampling Frame | Type | Remote Sensing | GIS | GNSS | Ref. |
|---|---|---|---|---|---|---|---|
| Africa | | | | | | | |
| Ethiopia | | List | Enumeration Area Frame from population and housing census | | | | [40] [41] [42] [43] [44] |
| | | Comunity | Enumeration Area Frame | | | | |
| | | Area Frame | Enumeration Area Frame (PSU) and segments of size 40 ha (SSU) | Satellite imagery used for stratification | GIS software used | Maps and GPS are used to prepare the information and locate the segments. | |
| Marruecos | | List | | | | | [45] [46] [47] |
| | | Area Frame | Rectangular PSUs, divided in segments (SSUs), selected with SRS. Segments adjusted to natural borders | Photo-interpretation on the orthorectified XS images Spot 5, 10 m | Frame building with GIS Generation of rectangular zones (PSUs) | | |
| Nigeria | Kaduna State | Area Frame | Land use strata / block /random points | Satellite imagery used for stratification an block construction | GIS used for construction | GPS used for point localization | [10] |
| Tanzania | | Area Frame | Cross points of latitude and longitude | Google Earth | Web site | | [48] |

# 4. The role of Information Technology Systems (Remote Sensing, GIS and GNSS) in setting up a Master Sampling Frame

As mentioned previously, a Master Frame must work as basis to perform any kind of sampling and census over a determined sector [5]. The construction of a sample frame for the rural sector implies the integration of crop and yield surveys (Agricultural Survey Samples), with surveys about the socioeconomics, demographics, and household health, (Household Survey Samples) characteristics in the rural environment. Normally, the construction of a Master Frame does not start from zero, since they are often built over previous statistical works. For example, in the case of Ethiopia, the construction of a Master Frame required the List Frame used for collecting agricultural data and the list of enumeration areas used for population and housing census [49].

Pre-existing frames can be of various types: lists, areas, or mixed, and can be found digitalized or geo referenced. For example, the Population and Housing Census is usually formed by a list frame of enumeration areas delineated during the population census cartographic work. The enumeration areas are geo-referenced [50]. It is and advantage to rely with information concerning the different elements (farms, households, plots) that make up the frame, that are located in space (geo referenced), in favor of an optimized construction and use of the frame [5].

The first step to build a Master Sampling Frame is the gathering of pre-existing information about statistical operations made in the sector of interest. This information is usually made up of several data type:

1. Lists, this is an enumeration, generally in a column, of the individuals that compose the population with certain characteristics of them that can be useful for the sample design and selection. In the agricultural sector it is often to use farmer lists from agricultural census. Sometimes this information is geocoded (eg zip codes), allowing their location.
2. Superficial units ordered in some form (area frame), as basis for sample selection. In the case of household samples, the territory is divided in enumeration areas (EAs) which are used as primary sampling units (PSU). In the preparation process of the frame a list of households in the selected enumeration areas is obtained. These households constitute the secondary sampling units (SSU). Usually surface elements are georeferenced.

Additionally it is necessary to count with auxiliary geographic information such as administrative boundaries at different levels (national, regional, local, and infra-local), roads, railways, rivers or coasts. The administrative boundaries often do not match with clearly identifiable elements on the territory.

The elements that establish the frames, both agricultural and households, can be superficial units or not, also they can be geo referenced or not, and they can be found in digital support or not. The frames with geographic/superficial basis may have been developed from material in paper support (maps and orthophotography) and therefore not be in digital support.

The arrangement of the information generated in the construction and management of Sampling Frames makes necessary to appeal for tools that allow the input, storage, manipulation, and analysis of this information in digital support. Sometimes the basis information it is not found in digital support, which implies the need to digitalize. Since the statistical units (EAs, PSU, and SSU) to be used have an essential geographic component for the proposed objectives in the construction of the Master Frame, it is essential to manage the activities in a Geographic Information System (GIS).

As proposed by Vogel (see figure 1), the construction of a Master Sampling Frame, requires the digitalized input of the Enumeration Areas (EAs) and Administrative Areas in the Information System; and also a land cover territory classification or soil usage has to be added to these areas. This is where remote sensing is a tool of first order.

Another element revolutionizing geo-referenced data acquisitions are GPS systems. The GNSS equipment offer topographic and cartographic information more precisely and at reasonable costs, becoming an important tool to build Sampling Frames, and also to locate the elements that form it.

The transition of the activities to build Area Frames based in physical support (paper and orthophotography) to digital support using GIS, with the use satellite imagery and global positioning systems for the territory stratification, have meant a time and resource decrease necessary to build the area frames.

In the following epigraphs the possible contributions of each system considered is analyzed.

## 4.1. Remote Sensing (RS).

Remote sensing is an important tool for agricultural statistics. Its use is focused on two important aspects: (i) sampling design and (ii) improve the estimates. Regarding the sampling design, remote sensing could be of interest in TWO aspects [51] [52]: (a) in the process of frame building, and (b) design optimization.

### 4.1.1. Sampling design.

**a) Area Frame construction**

The use of remote sensing is of especial interest in the Area Frame building process. This phase has been traditionally done from aerial photographs, in some cases not ortho-rectified; particularly, aerial photographs continue to be used in area frames made of square segments [52]. Since 1964 the U.S. NASS has been using area frame sampling and since 1978 it is using remote sensing for operational construction of the Nation's Area Sampling frame for agricultural statistics [53] [54].

The use of satellite imagery has advantages regarding the use of aerial photography. Among these, it is noticed that satellite imagery are often more recent than the available aerial photographs, since these photographs may have been obtained several years before the construction of the frame. Also is noteworthy that satellite imagery usually has several bands or channels, which is demonstrated to be useful for agricultural applications, especially to elaborate thematic maps through classification techniques [55].

The main use of satellite imagery regarding the creation of area frames is its use in the territory stratification process [52] [51]. The purpose to stratify a population is to make groups of individuals (stratus) as homogeneous as possible, so the variance in a stratus is small. To accomplish this, the stratification criteria, the number of stratus, and how the individuals are assigned to each stratus, has to be decided. The territory stratification, normally in soil use levels, is the main utility in the frame building process. Several experiences have been done to establish automatic classification algorithms to be used for territory stratification, without satisfactory results. The MARS Project tried to develop algorithms of automatic segmentation of panchromatic and multi-spectral satellite images for automatically detection for individual field limits. The developed algorithms did not provide adequate results for recognition of boundaries between segments [57].

Usually, the stratification process during the area-frame building is done by image photo-interpretation using specific image management software, such as the informatics photo-interpretation tool POPOLUS( Permanently Observed POints for Land Use Statistics ) used in the system for the definition and stratification of the Italian statistical frame [32]. The Global Land Cover Network (GLCN) has developed informatics applications oriented to ease the actitivities of land cover mapping [58] Land Cover Classification System (LCCS) [59], Geographical Vector Interpretation System (GeoVis), MApping Device–Change Analysis Tool (MAD-CAT), Advanced Database Gateway (ADG). This software has been employed to build the area frames in Ethiopia, being the land cover classes verified with GPS [44]. Morrocco has developed an application to manage the update Jobs of their área frames using satellite imagery (application sig pour l'automatisation de la methode "d'échantillonnage a base areolaire") [60].

Vidhute et al.[56] recently have made a review on the use of Remote Sensing and Geographic Information Systems in land use planning and decision support systems. Vidhute et al.[56] analyse the techniques used by researchers to analysis the use / land cover information in any area. The main techniques include:

- Supervised classification. In these methods we assume that we have prior knowledge to classify land (eg land cover types in specific sites). The most useful classifiers of this type are: maximum likelihood classifier, minimum distance classifier, parellopiped classifier and mahalanobis classifier.
- Unsupervised classification . In these methods we have no prior knowledge of the area to be classified. The two common types of these classifiers are K-means clustering and ISODATA (Iterative Self-Organizing Data Analysis
- Hybrid classifier. These metohds are a combination of supervised and unsupervised
- Fuzzy classifier. Classification methods based on Fuzzy Logic
- Normalized data vegetation index (NDVI). These methods consist in calculating indices that make use of the differences in the spectral reflectance of the plants, ie strong absorbance in the red and strong reflectance in the near-infrared part of the spectrum

The spatial, spectral, and temporal, resolutions of the sensors are an important factor to take in account for the activities of building or updating the area frames. Nowadays, there is a great of satellite imagery with different resolutions. Regarding the building process of an area frame, the spatial resolution of the imagery most used have been 30m (Landsat [54]) and 5 to 10m (SPOT [44], [60]).

On the other hand, the construction and maintenance of the area frames has passed from physical support (paper) to a digital support. The use of satellite imagery is an additional advantage by having its material in an optimal support to be stored and managed digitally in GIS.

**b) Design optimization**

The design optimization of sampling design implies its improved efficiency, which is related to reducing errors due to sampling. Addressing an sampling efficiency-improvement problem has to consider the relationship between the sampling error and the costs of obtaining those estimations; this means that the most efficient survey will be the one that offers a determined precision level at the lowest possible cost, or alternatively it will be one that achieves the best precision level at a given cost [61].

Remote sensing may have an important role in many features of sampling design. The use of information from satellite imagery can be of especial utility to optimize the size of the sampling unit, to propose the type of sampling to perform or to fix the number of stages to do [51].

**I. Sampling unit size optimization**

The optimal size of the sample has been theoretically addressed in many studies. The problem is usually approached considering that the most efficient sample size is one that makes minimal the variance estimator for a given cost; or that minimizes the cost for a given variance. The sampling variance depends of the variability between and within sampling units. Different alternatives have been proposed by many authors to address this issue. Some authors have considered using the variogram function to study this variability [62] [63] [64] [65] [66].

The calculation of spatial variability functions requires having previous information of the variables of interest localized in space. Sometimes the information from previous studies is not enough to estimate the correlogram. Also, sometimes it is necessary to rely on autocorrelation functions at short distances, which is difficult to obtain from data. In these conditions the autocorrelation functions can be derived from the information of the satellite imagery [51]. An important issue to consider is if the correspondence between the photo-interpretation (classification) of the images and the variable of interest is perfect [52].

**II. Selection of type of sampling and number of stages**

Many authors have studied the behavior of the spatial autocorrelation function, with the aim to evaluate the conditions in which the systematic sampling provides more precise estimations than the simple random or stratified sampling. The visual analysis of the correlogram function can be of special interest for evaluating the type of sampling to perform, since it may offer information of the concavity of the function, or the presence of periodicity, and suggest the choice of a stratified or systematic sample [67]. If the correlogram is a regular decreasing curve a systematic sampling approach would be adequate; meanwhile if the curve presents a determined periodic structure, it would be recommended that the sampling was not systematic.

Additionally, the correlogram analysis could be useful by suggesting the use or not of two-stage sampling, as well as to determine the optimal combination between the sizes of the primary and secondary units [67].

### 4.1.2. Improve the estimates

There are many studies using remote sensing data for improving the estimates obtained from area sampling. Gallego in 2004 [68] makes a fundamental review of the state-of-the-art on land cover area estimation using remote sensing. He conducted an overview of different ways that satellite images could be used to estimate land use. From the viewpoint of estimating, two application groups can be considered:

A) Methods in which the basis of the estimation are remote sensing data, while ground data, usually obtained from spatial samples, are only used as auxiliary information. These estimates are obtained in the processes denominated supervised classifications where ground samples are used as training sites of the classification.
B) Methods in which information obtained by remote sensing (exhaustive) is combined with information obtained from the samples (accurate). These methods include regression, calibration and small area estimators.

Grace et al.[69] proposed to obtain accurate estimates of cropped area for Guatemala and Haiti using an area frame sampling approach and very high resolution satellite imagery (Orbview and WorlsVieW). They use point-based interpretation for images taken during the major cropping seasons. Percent crop is evaluated using blocks of 5 x 5 km within which a regular grid of points spaced 500 m is superposed. A Generalized Additive Mixed Models with a long link is used for estimating cropped area using geophysical and demographic data as independent variables.

Luiz et al.[70] developed a method for estimating soybean crop area on a regional scale in the State of Rio Grande do Sul (RS), Brazil. The proposed method (Geosafras) combines statistical sampling techniques with information obtained from satellite images.

Kussul et al.[71] evaluated the use of various types of satellite images (MODIS, Landsat TM, AWiFS, LISS-III and RapidEye) combined with a field survey on a stratified sample of square segments, for la crop area estimation in Ukraine. The best results were obtained with neural networks classification (MLP: Multi-layer perceptron) and Landsat TM images.

Baig et al. [72] propose an application of area sampling frame and remote sensing to improve crop area estimation in a mountainous region of Pakistan bordering with Afghanistan. LANDSAT 5 satellite images and sampling data are used in unsupervised and supervised classifications in order to obtain land use estimation. The results of this study were compared with results derived by the Pakistan Federally Administered Tribal Areas secretariat. It can be concluded that the reliability and the accuracy of the system are acceptable.

Remote sensing techniques used in conjunction with a classical area frame sampling approach are also useful for assessing deforestation rates. Oduori et al.[73]using semi-automatic tree detection algorithm, demonstrate the utility of the combined use of high resolution satellite imagery and spatial sampling for these purposes.

Pradan [74] develops a GIS tool for crop area estimation based on frame sampling, remote sensing or a combination of both. This tool aims to support crop forecasting systems at a regional level. The implemented tool is useful in the area frame design and in the estimation of the cultivated area of major crops.

Ambrosio et al. [75] proposed an Empirical Best Linear Unbiased Predictor Estimator (EBLUP) for estimating crop acreage in "small areas" using ground survey and satellite images. The proposed estimator is compared with survey regression, synthetic regression, and direct expansion estimators.

Other methods used for estimating land use are direct expansion and regression estimator. These are used by Deppe [76] in order to establish forest area estimates within a test site area in the state of Rio Grande do Sul, Southern Brazil.

## 4.2. Geographic information system

The construction, management and maintenance of a Master Sampling Frame require efficient instruments for acquisition, processing and management of the information generated during the process. Most of the elements that are part of the frame, as well as the information to be acquired from samples, have a geographic component (location on the territory). Therefore it is necessary to develop specific tools for storing, handling and analyzing such information. Since the mid-80s Geographic Information Systems have been developed. These systems consist of a series of physical elements (hardware), logical elements (software) and personnel, targeted at the acquisition, storage, processing and representation of geographic information, for a concrete purpose.

The use of GIS in agriculture has important applications which include monitoring of crops, management or precision farming practices and, of course, area frame surveys supporting [56].

Most operational area frames have been developed into GIS systems (see Table 1). Projects have also been developing GIS applications aimed at the construction or management of Sampling Frames information. The “Direction de la Stratégie et des Statistiques (DSS)” of the Ministry of Agriculture of Morocco has developed applications to manage works related to area frame. The object of one of these applications is to facilitate update jobs of their area frames using satellite imagery (application sig pour l'automatisation de la methode "d'échantillonnage a base areolaire") [60]. In the same spirit, Pradan [75] developed GIS tools that assist in the area frame design, selection of sample and improve crop area estimation combining remote sensing and sampling data.

Sharifi et al. [77] developed an information system to support crop forecasting of major agricultural commodities in Iran. The system combines estimates from an Area Frame Sampling, Remote Sensing and growth simulation models.

The geo-referenced data is the basis of a Geographic Information System. There are three components of this data that are of interest, which are: localized elements in space, the attributes of the elements, and the existing relationships between elements. Traditionally, the geo-referenced data have been assigned with two components, a spatial component (location) and a thematic component (attributes). The spatial component can be of various types (points, lines polygons) which coincide with the different type of area frames proposed, based in points, transects, regular polygons, or polygons according to permanent boundaries. In the design of Geographic Information System for the management of a Master Sampling Frame it is essential to considerer, apart from the spatial elements, the attributes that each of those elements will have and the relationships that will appear between them. The functions of a GIS can be framed in four types:

A. Data Acquisition/Input.
B. Information management (storage/maintenance)
C. Data analysis and processing
D. Presentation of results

The role of each function in the construction of a Master Sampling Frame is the following.

**A. Data Acquisition/Input.**

One of the main advantages of a GIS for information management is its ability to integrate information from different sources and with different formats [5]. Hence, in one system vector and raster data can be integrated. Concerning the formats, GIS allow the input of information from different remote sensing systems, airborne sensors (multispectral, hyperspectral, radar, and LIDAR), scanned paper-based documents, as well as information acquired with topographic or GPS instruments.

The Master Sampling Frame construction is usually done over precedent frames (list and area): Therefore it is important that the system allows the use of all the previous generated information. An important issue to consider when treating existing geographic information is the reference system used by different sources of data. It is necessary to considerate both, the datum and the projection system. Since the sample selection is usually done proportional to the surface, it is recommended to use a cartographic projection that does not distort the land surface. The European Commission recommends use of Lambert Azimuthal Equal Area (ETRS89-LAEA) projection, for statistical analysis and for map display purposes [51].

It is important that system has tools that allow transforming from one spatial reference to another; hence all the information adjusts in a common system.

The information capture equipment may also be varied. Typically, the information is introduced from digitalized cartography or geo-referenced images, but GIS systems may also incorporate information using other types of peripherals such as cameras, personal digital assistant (PDA), or tablet computer (Tablet) with mobile GIS technology and GPS for geolocation [77] [78].

**B. Information management (storage/maintenance)**

A system is an entity in continuous evolution and acquisition of new information, consequently it is important to keep information updated; as well to establish a historical file of the previous used information. In the way the data and procedures of the system increase, it becomes necessary to have an information storage management system.

**C. Data analysis and processing**

The analysis and processing of information functions introduced in the system are especially important at the moment of setting up the Master Sampling Frame. The whole work scheme proposed by Vogel [6] and exposed in figure 1 can be implemented using GIS tools for the analysis and processing of the information. Similarly all the remote sensing methodologies proposed for setting up a Master Area Frame are susceptible to be applied using GIS tools. GIS tools that could stand to construct a sampling frame include:

- Satellite image classification using various classification methods.
- Spatial variability calculation (semivariograms and correlograms).
- Spatial analysis.
- Projections and Transformations

**D. Presentation of results**

The presentation results functions, in the case of sampling frame, are very important, since once the frame is defined and the samples is drawn, the graphic material has to be prepared for the field work. This material may be required in physical support (paper) as well as digital support to perform field operations with portable equipment (PDA or Tablet).

Portable, hand-held computers may be particularly useful in collecting data. Combined with GPS, bar coded or transducers can facilitate the data geolocation and reduce human errors introduced. If the supplied information to the personnel in charge of the field data acquisition is correct, and the supplied equipment allows an easy location of the target object, then an on-time gathering is guaranteed. The captured data can be easily downloaded and even be sent immediately through mobile-data new technologies. The communication can be bidirectional, the field staff receives the material and returns it filled in a telematic way. The whole process additionally implies that the information is transcribed just once, avoiding possible errors due to handling of the information.

The use of PDAs to capture field information has been tested in sampling frame construction projects in Ethiopia, even though the project's main objective was the evaluation of GPS use for area measurement [79]. In this sense, Keita [80] evaluates the use of portable hand-held computers as tools in agricultural statistics, concluding that this type of devices allow a faster data recollection and with improved quality due to the reduction of the data input stages. On the contrary it is necessary to train the personnel who will use the equipment and this implies an additional cost for data capture.

## 4.3. Global Navigation Satellite Systems.

As it was mentioned before, the construction of a Master Sampling Frame requires determining the location over the territory of its elements. The term, geo-referencing, refers to establishing the location of an element over the land surface employing a determined cartographic projection and a coordinate system. Geo-referencing requires the use of tools that permit giving coordinates to those elements. Among those tools, GPS systems have become a popular option not a long time ago.

In Master Sampling Frames, the main applications of GNSS systems are:

- Location of / Navigation to points on the ground
- Area Measurement
- Geocoding of elements (eg Households)

The location of points over the terrain during field activities of area sampling, are usually done with aerial (orthorectified) photographs, topographic maps, compasses and GPS [81]. Not long ago, the use of hand-held GPS to locate points was not recommended due to their lack of accuracy and elevated cost. Due to the improved accuracy and reduced prices of GPS equipment, its utilization in the work location of sampling elements seems advisable.

Regarding the area measurement with GPS equipment, Keita [80] [82] evaluates the use of GPS instruments under different conditions (meteorological, or canopy situation). GPS systems have allowed data collection more accurate and consistent than estimating locations or area using paper maps or a compass and distance measurement.

Palmegiani [83] analyzed the statistical relevance of measuring surfaces of cultivation parcels using GPS respect to the traditional method using compass and meter. Among other conclusions, the author states that the measurement of cultivation parcels using GPS may be significant to reduce the costs of agricultural surveys.

Aguilera et al.[84] evaluates and proposes the use of equipments based on GPS+PDA technology, designed for agricultural or forestry surfaces. The proposed equipment may extend its use to multiple situations where “in situ” information recollection is needed. The accuracy in surface measurement depends of the surface of the parcels measured, being the relative errors higher as the area decreases.

Geocoding is the process of giving coordinates to elements that have a determined codification for their localization, for example postal addresses or administrative division codes (counties, provinces). In the construction of sampling frames where householders are included, the geocodification of these, which are normally identified by a code or a postal address, is a very important factor to take in account. NASS have proposed geocoding the centroids of the 9 digit zip codes associated with the mail address households [85]. The GPS devices are important tools to execute the geocoding of the elements of a sampling frame.

## 5. Proposals of further steps on research topic

1. Identification of different typologies from countries/regions regarding landscapes, economical structure, size of agricultural exploitation, the crops and livestock spatial distribution, households and social diversity.

2. Characterization of variables of interest for the different typologies identified in order to setting up the Master Sampling Frame c (the following could be mentioned as examples: the enumeration areas superficial dimension, the number of houses in every enumeration area, main crops, cropping calendar).

3. Determination of the recommended type of frame for each type of landscape: point frame, square segments, segments with physical boundaries, etc.

4. Analysis of the remote sensing requirements for sampling frame construction:

   a) Identification of suitable sensors.

   b) Identification of the ideal dates for imagery acquisition, based mainly in the type of crops and their calendar.

   c) Identification of the appropriate spectral and spatial resolutions.

   d) Identification of the adequate land use/ land covers information analysis techniques for the construction of the Master Sampling Frame.

   This will be done for each typology and for the provided applications, in the frame setting up (land use / land cover determination for stratification purposes, design optimization, graphic documents for ground survey elaboration), as well as for improved estimates.

5. Characterization of the different information sources, available or needed, for the construction of the Master Sampling Frame (previous sampling frames, cartographic material – paper maps, digital maps, orto-photographs , previous satellite images), as well as the appropriate scaling.

6. Design of automated GIS procedures to model Master Sampling Frames. Eg:

   a) For point frames a generator of random or systematic locations of points.

   b) Determination of optimal block and segment sizes from the spatial variability for square or lattices segment frames.

   c) Determination of the optimal segment size from the spatial variability of the variables of interest, for frames built over permanent boundaries.

   d) Development of procedures for the automatic extraction of permanent boundaries.

7. Design of processes for field data collection, geolocation of elements and surfaces measurement using hand-held computers (PDA) and GNSS equipments.

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