Chapter 2
Overview and Brief History

2.1 Introduction

In recent decades, there has been an increasing consensus regarding the challenges of applying statistics to agricultural surveys (Benedetti et al. 2010). Although agriculture is assuming a more marginal economic role in western countries, if measured in terms of the percentage contribution to a country's GDP, it is essential to many people's livelihoods.

Agricultural development is also fundamental for monitoring issues relating to poverty, food security, and environmental sustainability. Monitoring agricultural resources is crucial to those countries where population growth is leading to an increase in agricultural production. The prompt availability of updated information is important for policy makers, who need to develop, promote and ratify structural and functional programs in the agricultural sector.

Pertinent agricultural statistics address all the requirements outlined above. The term *agricultural statistics* includes statistics on agricultural products, forestry, fisheries, livestock, and food safety. The definition includes consideration of land use, and the culture of a living organism through more than one life cycle and ownership (Everaers 2010). Different research areas are acknowledged in agricultural statistics: sample surveys, experiment design, and biometrical techniques, amongst others. For a comprehensive review of statistical methods in agriculture see Benedetti et al. (2012).

When specifying the purposes of an agricultural sample survey, it is necessary to outline some common terms that are typically used in the agricultural sector (FAO 1996). An *agricultural holding* is an economic production unit under a single management that is involved in agricultural production activities. A *holding parcel* is any piece of land entirely surrounded by other land, water, road, or forest that does not form part of the holding. A parcel may consist of one or more fields adjacent to each other. A *field* is a piece of land in a parcel, which is separated from the rest of the parcel by easily recognizable demarcation lines, and on which a

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specific type of crop or crop mixture is cultivated. The *holder* is a civil or juridical person who makes the main decisions regarding the use of resources and manages the agricultural holding. The holder has technical and economic responsibility for the holding. They may directly undertake all the responsibilities, or delegate responsibilities to a *hired manager*. The *respondent* of an agricultural survey is the person (i.e., the holder or manager) who has provided data about the holding. For further details about these definitions, the reader can refer to Chap. 5.

The aim of an agricultural survey is to estimate several variables of interest for the total survey area. The estimate of each variable is obtained through an inference procedure using the values in all, or a sample, of the reporting units (typically the holdings or land areas). The survey area may be the whole country, a province, or a region.

The layout of this chapter is as follows. Section 2.2 is devoted to an overview of using spatial units when sampling, and describes the advantages and disadvantages of this sampling approach. Section 2.3 contains a review of the main agricultural surveys based on spatial units. Finally, the last section concludes the chapter.

2.2 The Use of Spatial Units When Sampling Natural and Environmental Resources

The importance of sampling spatial units has recently been acknowledged for various practical problems in geographical and environmental studies. In most cases, spatial units are defined across a geographical domain partitioned into a number of predetermined regular, or irregular, shaped locations, i.e., pieces of land territory. Sample information is used when a complete enumeration is too expensive, with the usual operations for estimating the distinctive features of a given population.

In standard sampling theory, spatial units have traditionally been represented as a mosaic of areas in which individual primary units are considered to be identical members of the same population (Haining 2003). In the first stage of a multi-stage sample design, the sampling frame consists of a number of large aggregate units, each of which contains sub-units. We will define a first-stage unit as a primary sampling unit (PSU). The investigator selects a probability sample of PSUs, and then proceeds to the second stage of sampling, in which a probability sample of sub-units is selected from each PSU. These elements are defined as secondary sampling units (SSUs, see Sect. 6.6).

Data relevant to each PSU (see the next paragraph for some examples) are frequently assumed to be independent. Therefore, they are selected so that the second-order inclusion probabilities are as close as possible to the product of the first-order probabilities.

When population units are geographically distributed, classical random sampling strategies may be inefficient. In fact, nearby locations tend to have more similar attributes than distant ones. Random units might be clustered in some areas and missing from others, and may potentially miss spatial hotspots. In this case, the choice of neighboring locations adds less additional information about the target area. So, it is clear that sampling schemes for spatial units cannot be reasonably defined unless we take spatial dependence into account (see Chap. 7 for a detailed description of the key topic of spatial sampling).

The next step when designing sampling schemes for spatial units is to recognize the existence of fundamental arbitrariness when aggregating areal data. This has been referred to as the modifiable areal unit problem (MAUP, Openshaw 1977, 1984; Arbia 1989). This uncertainty seems to be particularly important because areal units are not generally defined for the particular purpose of spatial data analysis, but on the basis of some other exogenous criteria. This means that data are available with respect to a given spatial configuration, whose structure is not necessarily based on the underlying model of spatial variation.

Agricultural sampling methods can be based on list or spatial reference frames (see Chap. 5 for more details). Designs based on a list frame are the most commonly used sampling procedures for agricultural surveys. The list frame is produced by an enumeration of elements of the population under investigation. In agricultural surveys, this is often formed by holdings or holders addresses.

A spatial[1] sample survey is a study in which the final stage-sampling units are land areas. The selection probabilities are generally proportional to their area, and the land areas are generally denoted as segments. The segments of a spatial frame can be areas (i.e., portion of territory), points, or transects (i.e., lines of a certain length). The sampling units should not overlap, and must cover the entire survey area under investigation.

List and spatial frames have advantages and disadvantages. In particular, list frame surveys are cheaper, because the sampled farms provide a large amount of information on crop area and yields, livestock, inputs, and socio-economic variables, and use only one interview.

Spatial reference frame samples (Cotter et al. 2010) are better protected against non-sampling errors that are caused by the frame having missing or overlapping units. They do not exhibit problems linked to gaps (i.e., bias of the estimates). It is also possible to use a spatial frame to update and verify the rate of coverage of existing archives on farms. Furthermore, the researcher can use auxiliary information (e.g., remote sensing), can issue timely and higher precision estimates on cultivated areas and expected production, and can reduce the burden on farmers. Finally, spatial sampling displays longevity of the frame (only updates for land use changes are necessary), is versatile (multiple variables can be considered in one survey), is objective (land cover/land use and measures of areas are directly observed by surveyors in the field), and has a low non-response rate (only for unreachable areas). The major disadvantages are the high cost of setting up the

[1] In literature, this frame is commonly called an area frame. We consider this expression to be misleading, and in this book we prefer the terms spatial reference or geo-coded frames.

frame and sample selection, and the considerable cartographic requirements for constructing the frame (i.e., maps, satellite images, aerial photos). Additionally, the spatial frame is not suitable for cultivations with high spatial variability (i.e., scattered), it can have limited precision for estimates over small areas or highly concentrated land classes, and it requires well-trained enumerators, high-tech methods, and qualified office staff and statisticians. For further details about spatial frame see Chap. 5.

Obviously, the narrative of this book will be mainly related to the use of the spatial reference frame.

2.3 Examples of Agricultural Surveys Based on Spatial Reference Frames

Spatial frame surveys are common approaches for gathering land cover and land use data. Land cover is the physical cover of the earth's surface, while land use is the socio-economic function of the land.

Spatial sampling is a statistical method (EUROSTAT 2000), in contrast with mapping approaches (for example, the CORINE Land Cover project). The estimates are computed using observations of sample units, and used as a valid generalization without studying the entire area under investigation. Several practical examples can be found in the *June Area Survey* (JAS) by the Department of Agriculture of the United States, the *Land Use/Cover Area Frame Statistical Survey* (LUCAS) by the European Commission, the *AGRIT* program by the Italian Ministry of Agriculture, and *Utilisation du territoire* (TER-UTI) by the French Ministry of Agriculture. The main characteristics of these surveys are explored below.

2.3.1 JAS

The National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (USDA) has developed spatial sampling frames since 1954, as a tool for collecting information concerning crop acreage, cost of production, farm expenditures, grain yield and production, and livestock inventories (Nusser and House 2009; Arroway et al. 2010). The main spatial frame survey organized by NASS is the *June Area Survey* (JAS). This mid-year survey provides area frame estimates, primarily of crop acreages and livestock inventories. JAS also includes an estimate of the number of farms in the United States.

The information collected about specific products varies from state to state. All contributing producers provide information on their total acres, acres planted with specific commodities, and the quantities of grains and oilseeds stored on a farm.

JAS is based on a spatial frame of areal typology, and is conducted annually. All land in the United States, except Alaska, is stratified by land use within a state.

Because the types of crops and livestock can differ widely across a state, land is divided into homogeneous strata: intensively cultivated land, urban areas, and range land. The general strata definitions are similar for the different states. However, minor adjustments may be made to the definitions depending on the specific requirements of a state. Each stratum is further divided into substrata by grouping areas that are agriculturally similar. Within each substratum, the territory is divided into PSUs.

A PSU completely covers all agriculture activities occurring within it, and, consequently, all farmers in the state. Each PSU is divided into segments, which are roughly a square mile in area. A sample of PSUs is selected, and one segment is randomly selected from each selected PSU.

Field interviewers divide all the selected segments into tracts, where each tract represents a unique land operating arrangement. Each tract is labeled as agricultural or non-agricultural. A tract is considered as agricultural if it has qualifying agricultural activity either inside or outside the segment. Otherwise, it is labeled as non-agricultural. An agricultural tract is classified as farm if its entire operation in sales (or potential sales) consists of at least \$1,000. All non-agricultural tracts, and agricultural tracts with less than \$1,000 in sales, are classified as non-farms.

Each year, approximately 3,500 segments are selected for inclusion in the sample. A selected segment is in the sample for 5 years. Thus, each year, the sample contains approximately 11,000 segments.

The JAS design is a probability-based sample. Each tract has a first-order inclusion probability π_i, and an expansion weight $d_i = 1/\pi_i$. Within each farm tract, a proportion of a farm is observed and defined as t_i (tract acres/farm acres). The current JAS estimate for the number of farms (NoF) is defined (Lamas et al. 2010)

$$NoF = \sum_{i=1}^{l} \sum_{j=1}^{s_i} \sum_{k=1}^{n_{ij}} d_{ijk} a_{ijk}, \tag{2.1}$$

where $i = 1,\ldots, l$ is the stratum, $j = 1,\ldots, s_i$ is the substratum, s_i is the number of substrata in stratum i, $k = 1,\ldots, n_{ij}$ is the segment, n_{ij} is the number of segments in substratum j that are in stratum i, d_{ijk} is the expansion weight (see the HT estimator in Sect. 1.2), $a_{ijk} = \sum_{m=1}^{x_{ijk}} t_{ijkm}$, x_{ijk} is the number of farm tracts in the given segment, and t_{ijk} is the proportion of observed farm tracts.

During the pre-screening, the survey personnel visit each newly defined tract to determine if it is a farm. In June, those tracts that have been determined to be a farm during pre-screening (approximately 35,000) are revisited, and crop and livestock information is collected through personal interviews.

This knowledge is subsequently used to provide state, regional, and national estimates for crop acreages, livestock inventories, and other agricultural items. Naturally, the procedures used to develop and sample area frames affect the precision and accuracy of the survey statistics.

2.3.2 LUCAS

Agricultural statistics in the European Union (EU) are produced by a close synergy between EUROSTAT[2] and the national statistical services of individual European countries. EUROSTAT defines the characteristics of the surveys (i.e., methods, nomenclature, accuracy, timing) and aggregates the data at the EU level.

The *Land Use/Cover Area frame Survey* (LUCAS, Gallego and Delincè 2010) is a project funded by EUROSTAT. It was initially developed to offer yearly European crop estimates. Over time, this survey has become crucial for policy makers, as it also provides land use data and is a valuable tool for environmental monitoring.

The main objectives of the LUCAS project are:

- To obtain harmonized data (and in particular, unbiased estimates) for the main land use and land cover areas, and any trends, at an EU country level.
- To increase the scope of the survey beyond the agricultural domain.
- To include aspects related to the environment, landscape, and sustainable development.
- To provide a common sampling base (i.e., frame, nomenclature, data treatment) so that interested member states can obtain representative data at national/ regional level.
- To evaluate the strengths and weaknesses of a spatial frame survey as one of the pillars of the future Agriculture Statistical System.

The precision is expected to be approximately (or better than) 2 % for the main categories such as wheat, cereals, arable land, permanent grassland, permanent crops, forests, urban areas, and inland waters.

The sample frame is executed at the country level, because it is not possible to create a regular grid over the entire European territory for statistical purposes. The sample frame is based on the official digital geographic data of the administrative boundaries and coastlines of Europe, available at EUROSTAT GISCO (the *Geographical Information System at the COmmission*).

LUCAS is a spatial reference frame survey based on points sampling. It was carried out in 2001 and 2003 for EU15.[3] It is based on a systematic sample of almost 100,000 points, grouped in clusters of 10. Systematic spatial sampling was chosen as the sampling design method. This is because LUCAS is aimed at providing multi-purpose information, and therefore needs to cover not only agricultural area,

[2] The Statistical Office of the European Communities.

[3] The EU15 was the number of member countries in the European Union prior to the accession of ten candidate countries on 1 May 2004. The EU15 comprised the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

but also all other types of territory. LUCAS has a double nomenclature: each point has a land cover code (57 classes) and a land use code (14 classes).

In 2006, the design was modified to a stratified two-phase sampling of unclustered points (Jacques and Gallego 2005). The stratification was performed by photo-interpretation of a 2-km grid of points in EU25.[4] The points placed on small islands were not considered in the sample (i.e., Baleares, Azores, the Canary Islands, Cyprus, Malta, and the Greek islands except Crete). A ground survey was executed on a sub-sample of 169,000 points covering 11 countries, over about 70 % of the area of EU25.

The sampling design was again modified for the LUCAS 2009 to give more importance to environmental and agri-environmental parameters. The 2009 sampling strategy aimed at providing precise estimates at the NUTS[5] 1 level. Following these requirements, a sample at EU NUTS 2 level has been selected. The regions (i.e., NUTS 2) were divided into two groups according to their total area. Group A is composed of NUTS 2 regions with a total area less than or equal to 500-km^2, while Group B contains NUTS 2 regions with a total area above 500-km^2. Additionally, Group B was partitioned into two parts: B1 contains regions belonging to the 11 countries already observed in 2006, and B2 contains regions from the other countries. For Group B1, some auxiliary information was available from the previous survey.

A different sampling strategy was chosen for the different groups. For Group A, the precision was not fixed, and the units were allocated to the strata in proportion to their size. For regions in Group B1, auxiliary information was used, and an optimal allocation (see Sect. 8.3) sampling scheme was formulated by exploiting a set of land cover classes. For Group B2, no information was available from the 2006 LUCAS survey. In this case, the auxiliary information was the land cover and land use data collected by the Corine Land Cover (CLC) program of the European Environment Agency (EEA 2007). The CLC classes were divided into 12 new classes. Based on this information, dissimilarity indexes were calculated among regions belonging to Groups B1 and B2 according to the city block distance

$$d = \sum_{c} |x_{cr} - x_{cr'}|, \tag{2.2}$$

where x_{cr} and $x_{cr'}$ are the areas of CLC group c in region r and r', respectively. The choice of maximizing the distance between each sample point (in both the same and different strata) was decided according to the 2006 survey, because it was shown to be efficient (Jacques and Gallego 2005). Conversely, points sampled in different

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[4] The EU25 (1 May 2004–31 December 2006) contained the EU15 countries plus Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia.

[5] The NUTS is a standard geocode classification for the subdivisions of countries for statistical purposes. The classification was developed by the EU. For each EU member country, there is a hierarchy of three NUTS levels.

strata can be close to each other and give some extra information on the spatial correlations between strata.

To reduce the effect of autocorrelation within and between strata, the basic sampling grid (2 km × 2 km) was divided into square (9 × 9, that is, 18 km × 18 km) blocks of 81 points. The set of points with the same relative position in the block is called a replicate. The replicates are numbered to maximize the distances with the previous ones. Replicates are then successively chosen until we have obtained the required sample size for this domain. Points are randomly selected from the replicate with the highest number. This selection method is combined with a panel approach (see Sect. 6.8). Finally, points with an altitude above 1,000-m are excluded from the second phase sample, because they are assumed to have little importance to agriculture.

The LUCAS 2009 survey included a soil module. A topsoil sample was collected for 10 % of the points. The objective of the soil module was to improve the availability of harmonized data on soil parameters in Europe.

Recently, EUROSTAT carried out the LUCAS 2012 survey in the European Union. The LUCAS 2012 covers all 27 EU countries. The fieldwork was carried out between March and September, 2012. The LUCAS 2012 data can be downloaded at http://ec.europa.eu/eurostat/web/lucas/overview.

2.3.3 AGRIT

The Italian AGRIT program (Carfagna and Gallego 2005; Postiglione et al. 2010) is a spatial sampling frame survey that aims at providing conjunctural estimates on areas, main crop yields, and main land uses. This survey uses spatial sampling techniques, in particular, point typology.

The method[6] is based on the integration of data collected from ground samples and remote sensing. The list is formed by a set of points (i.e., the point frame) that exhaustively covers the land. Each point has an operational dimension area: a 3-m radius circle centered on the point (covering approximately 30 m^2). If there are associations between different land uses, the observation area is extended to approximately 700 m^2. If there are different land uses, each (up to a maximum of three) is assigned to the point with a respective proportion according to a pro-rata criterion.

The sampling design is stratified into three phases. The sample of the first phase uses an aligned spatial systematic selection of geographical units. This list of units is denoted as the AGRIT sampling frame, and is formed by a regular grid of points (approximately 1,200,000). The resolution of the grid is 500 m, defined using the Gauss–Boaga coordinate system,[7] and completely covers the land under

[6] The technical details described in this sub-section refer to the 2005 AGRIT program.

[7] The Gauss-Boaga projection is a map projection used in Italy that uses a Hayford ellipsoid.

investigation. The sampling units for the second phase are based on a preliminary identification of zones of interest for analyzing the different levels of administrative division: province, region, and entire national territory. Finally, the yield estimates in the third sampling phase are calculated for the same geographical levels described above, but only for 12 different crops.

The land use archive for agricultural surveys may be derived from three different sources: a ground survey, interpretation of digital orto-photos, and remotely sensed image classification. AGRIT uses photo interpretation of remotely sensed images acquired from aircraft. This activity, which formed the hierarchical nomenclature of reference (on two levels, for a total of 25 labels), was developed within the *Permanent Observed POints for Land Use Statistics* (POPOLUS) project. The 25 POPOLUS classes were aggregated into six groups, and only four were sampled.

The first step when preparing the archive was the stratification of the first phase units. The points were stratified using 103 Italian provincial codes and 6 classes of land use, obtaining 618 non-empty strata. The strata codes for land uses are: arable land, permanent crops, permanent fodder land (altitude $\leq$1,200 m), permanent fodder land (altitude $>$1,200 m), wooded land, isolated trees and agricultural buildings, and other (i.e., artificial surfaces, water, non-vegetated natural surfaces). The target population for the selection of the second phase sample is composed of the points that display an agricultural activity. The criterion for the definition of the strata is conservative: all the points that have a potential agricultural interest are considered. Therefore, a random second phase sub-sample was extracted from the strata codes that are considered useful for AGRIT 2005 and each of the 103 Italian provinces. In total, approximately 150,000 points must be collected.

AGRIT 2005 was a multipurpose survey, and was defined to produce estimates with a predetermined sample error for a set of variables (i.e., areas of different crops). Bethel's algorithm (1989) was used as the allocation method in the sampling procedure. It is a generalization of Neyman's classic formulas for calculating the optimal sample size, in the case of stratified sampling (see Chap. 8).

Finally, the third phase sample produces the yield estimates. Bethel's algorithm was again used to determine the sub-sample size, using the variances of the yield of the previous AGRIT rounds. The sample contained approximately 60,000 points, located in different regions of Italy.

The survey has remained essentially unchanged across the years.

2.3.4 TER-UTI

The knowledge and monitoring of land use and land cover are old issues in France. The *Utilisation du territoire* (TER-UTI) survey is annually conducted by the statistical services of the French Ministry of Agriculture and Fishing. It collects data on land use throughout the whole continental territory, using a set of points constituting a representative sample of the territory.

The first survey on the use of agricultural land dates back to 1946. The design of that survey was based on the land surface from cadastral maps. In 1962, aerial photography was introduced, not as a support for the survey but as a tool for updating cadastral maps. From 1969, this design approach was generalized to all French departments.

The first TER-UTI was carried out in 1982. It was renewed in 1990 and 1991 to correct certain biases introduced during sample selection in 1982. Continuous time series are available for the years 1982–1990 and 1992–2004 for 550,000 points, except in 2004 when the sample was reduced to 155,000 points.

In 2005 the survey design was re-defined. Two main developments led the researchers to modify the survey. First, technical progress in the digitization of cartographic and geo-referencing points encouraged the re-definition of the sampling points TER-UTI, which were previously determined manually using aerial photographs. Second, the definition of the LUCAS survey by EUROSTAT (based on the same methodological principles as TER-UTI) encouraged a deep revision to produce consistent nomenclature, observation methods, and sample design. For these reasons, the French survey is now denoted as TER-UTI LUCAS.

The main objectives of TER-UTI LUCAS are:

- To determine, each year, the different classes of land cover and land use for the whole territory (agricultural, environmental, and urbanized) at different geographical levels (national, regional, and departmental).
- To monitor and to quantify the land cover and land use, and landscape structure changes.
- To provide a data source for other studies (agri-environmental indicators).
- To increase the sample (number of segments or number of points per segment).

The population under investigation extends to almost the entire national territory. The only restrictions are Guyana and Mayotte, which are not suited to this method because of their small sizes.

TER-UTI LUCAS uses a non-stratified two-stage sampling scheme, with points grouped in PSU. The PSUs are the segments, generally identified by a square area that varies from 1.5 km × 600 m to 1.5 km × 1.5 km. The second stage units are the points, which have a 3-m radius circle centered on the point (basic observation window) in the general case, or a 40-m radius circle (extended observation window) in the case of heterogeneous land cover. Points are spaced 300 m inside a segment. The two-stage sampling scheme is a compromise between the cost of the survey and the desired precision of the results. It presents almost the same precision as a one-stage sampling but is less expensive.

Data from this survey are used in a number of ways (Vidal and Marquer 2002). In particular, the data set has been used for the calculation of three indicators: a predominant cover indicator, a spatial organization indicator, and a temporal trend indicator. To compute these indicators, the points are grouped into three categories: natural, agricultural, and non-natural (i.e., artificial). Natural areas comprise rock and water, moorlands, grazing land, alpine pastures, deciduous forests, and coniferous forests. Agricultural zones include hedges, scattered trees, poplar stands, trails, perennial crops, vineyards, orchards, and grassland annual crops. Finally, artificial regions involve green artificial, paved, constructed or altered artificial.

For the predominant cover indicator, a grid is considered to have predominant cover if more than 50 % of its points belong to a specific type of cover. For the spatial organization indicator, each grid section is considered separately and a statistical method is used to determine the number of proximities between the three classes. Depending on the predominant proximities, each grid's land cover is classified as homogeneous or heterogeneous. For the trend indicator, standard trends are defined according to modifications in the frequency and homogeneity of the three components.

Conclusions

Changes to land cover and land use are important for capturing the evolution or dynamics of the countryside. The most feasible approach to surveying land resources on a national scale is to use statistical sampling. A complete survey is simply too expensive. A sampling based survey can also be repeated at fixed intervals to provide information about changes in land resources.

During recent years, the use of spatial reference frames has become more attractive for defining the sampling design. This approach appears to be suited to the analysis of agricultural data, which are often geographically distributed. In this chapter, we have outlined some survey examples that make effective use of spatial reference frames. This list is obviously not exhaustive. For other examples, the reader can refer to FAO (1998). It contains a very comprehensive description of spatial frame techniques (as well list survey methods), and includes chapters that consider separate countries and their individual implementations of geo-coded frames and crop surveys.

However, the first constraint when appropriately organizing a spatial frame is the availability of up-to-date cartographic material (i.e., maps, satellite images, aerial photos) that covers all the required land. The resolution of this material must be sufficient for stratification according to, for instance, the proportion of land cultivated or predominance of certain crops.

These topics, which are of crucial importance to the definition of effective spatial sampling for agricultural data, will be described in Chap. 3 (the Geographic Information System) and Chap. 4 (remote sensing tools).

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