A GUIDE TO SAMPLING

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50x2030 TECHNICAL PAPER SERIES #3

Contents

I. Introduction

The 50x2030 Initiative to Close the Agricultural Data Gap aims to strengthen national data systems so that they are better equipped to meet the data demands coming from global, regional, and national data reporting systems and obligations. In particular, countries adopting the 50x2030 survey approach will be well-positioned to produce official statistics using a sound methodology and report on critical agriculture-related Sustainable Development Goal (SDG) indicators. They will also be better able to understand the drivers of agricultural productivity and income, and their linkages with welfare and rural development. The 50x2030 approach integrates the collection of data on the basic features of the agricultural sector (including annual production figures) with a broader set of data on economic, environmental, and social factors of relevance to rural areas.

The 50x2030 Initiative proposes modular and integrated survey programs with the aim of monitoring and understanding agricultural systems. Key agricultural data, namely production, will be collected on an annual basis, while more in-depth agricultural data will be collected every three years. The system builds on the experience of FAO's Agricultural Integrated Surveys Programme (AGRIS) and the World Bank's Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA) program. As with those programs, it will become an integral part of national statistical systems.

As with any multipurpose survey system, the sampling design should be carefully elaborated to produce reliable estimates in a cost-effective way in order to fulfil the measurement objectives of the 50x2030 Initiative. This document discusses the key technical features of a suitable sample design for the survey programs proposed by the Initiative. Starting with the definitions of the populations of interest, it then discusses the development of sampling frames, stratification criteria, sampling size calculations, estimation procedures and sampling approaches over time. The final section covers sampling issues in relation to existing survey programs in countries that adopt the Initiative's survey system.

II. Overview of the measurement objectives and survey programs

II.A. Measurement objectives

The 50x2030 Initiative prioritizes the estimation of national statistics and critical, agriculture-related SDG indicators in countries of interest. In particular, the Initiative focuses on SDG 2 (Zero Hunger), SDG 5 (Gender Equality), and data collection for the computation of four high-priority SDG indicators:

- 2.3.1 – Volume of production per labor unit by classes of farming/pastoral/forestry enterprise size;
- 2.3.2 – Average income of small-scale food producers, by sex and indigenous status;
- 2.4.1 – Proportion of agricultural area under productive and sustainable agriculture;
- 5.a.1 – (a) Proportion of total agricultural population with ownership or secure rights over agricultural land, by sex; (b) Share of women among owners or rights-bearers of agricultural land, by type of tenure.

The survey program may also need to address additional indicators required at the regional or international level. For instance, African countries are required to report the indicators of the Comprehensive Africa Agriculture Development Programme (CAADP). The survey instruments promoted through the 50x2030

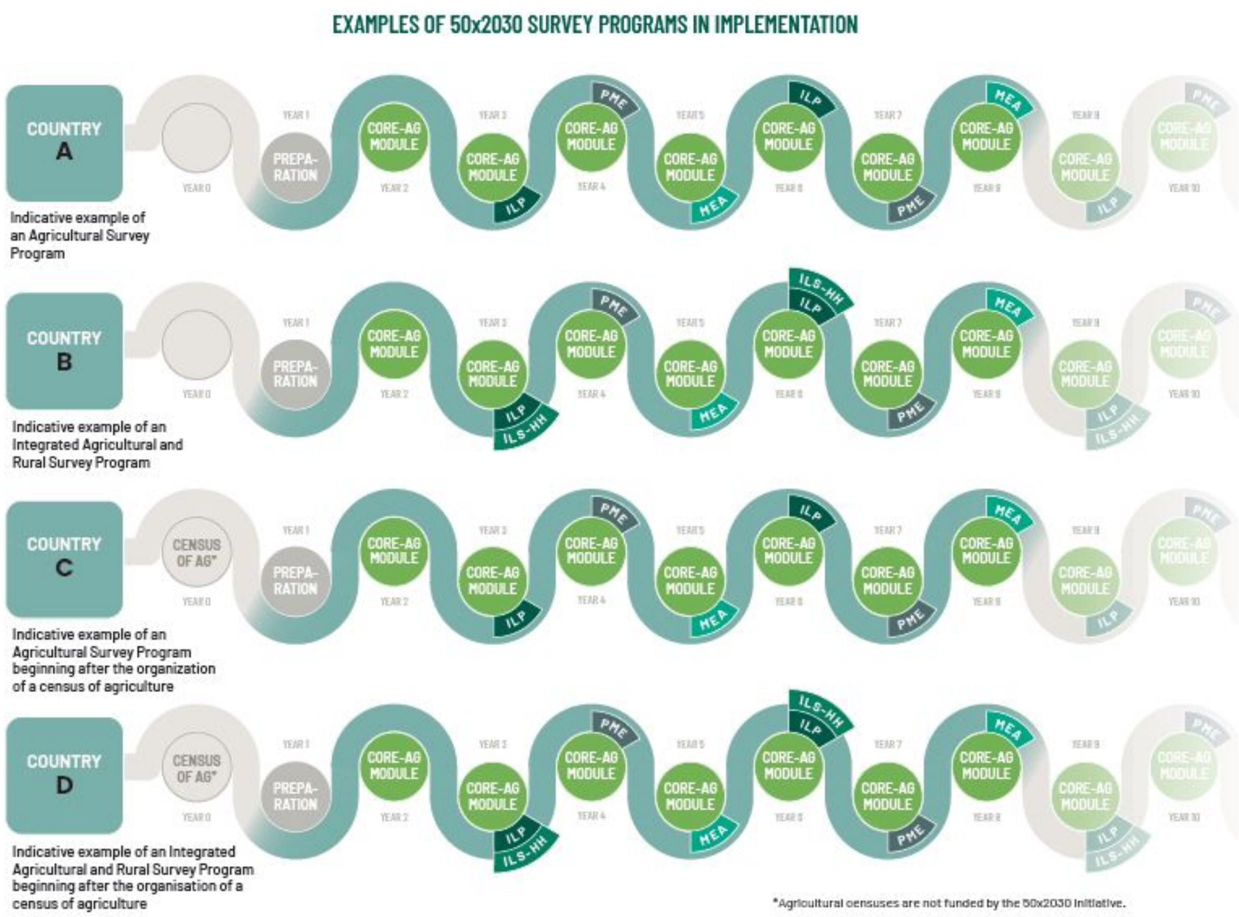
Initiative aim at addressing several CAADP indicators and can be adapted and expanded to include national priority indicators as well as additional SDG indicators (50x2030 Initiative, 2020). Covering such broad measurement requirements in a survey operation poses challenges that the sampling design should address.

II.B. 50x2030 Integrated Survey Programs

Two survey programs are supported by the Initiative: the Agricultural Survey Program (Agricultural Program) with only agricultural components, and the Integrated Agricultural and Rural Survey Program (Integrated Program) that integrates the agriculture components with a household survey component. Examples of the two survey programs are illustrated in Figure 1, although these may be altered according to country needs.

The 50x2030 Agricultural Survey Program is a modular survey system. It has an annual, core survey tool focused on crop, livestock, aquaculture, fishery, and forestry production (CORE-AG), and a set of specialized tools covering such topics as farm income, labor and productivity (ILP); production practices and environmental aspects of farming (PME); and farming-related machinery, equipment and assets (MEA). These specialized tools are administered at lower frequencies, as illustrated by countries A and C in Figure 1. Additional specialized tools may be added according to country needs and demand.

FIGURE 1. EXAMPLES OF THE 50X2030 SURVEY PROGRAMS

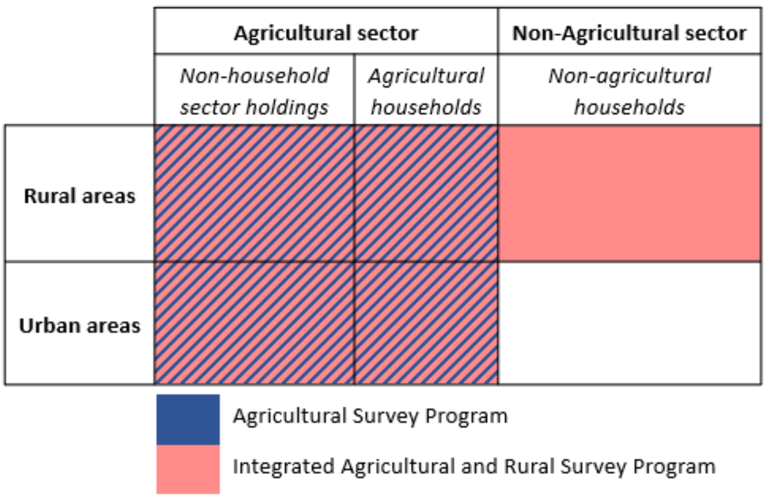


The 50x2030 Integrated Agricultural and Rural Survey Program follows the same logic as the Agricultural Program but integrates the agriculture tools with a household survey tool and broadens the target population to incorporate a sample of rural non-agricultural households into the system every three years (as illustrated in Figure 1, countries B and D). The Integrated model allows partner countries to better understand the drivers and dynamics of rural development, structural transformation, and their linkages with agriculture, as well as the linkages between agricultural productivity and income with aspects of welfare and livelihoods, such as educational outcomes, non-agricultural income, or shocks and coping. The Integrated Program achieves this through the combination of the Farm Income, Labor, and Productivity (ILP) questionnaire and the Non-Farm Income and Living Standards Household (ILS-HH) questionnaire, which are administered together every three years.

III. Populations of interest

In line with the measurement objectives of the Initiative, the target populations of the survey program are (i) all households in rural areas, and (ii) all agricultural holdings in the country. The Agricultural Program covers all agricultural holdings (in both the household and non-household sectors) as the population of interest, while the Integrated Program combines a household-based survey with a farm-based agricultural survey, covering all households in rural areas and all agricultural holdings as the population of interest, as illustrated in Figure 2.

FIGURE 2. COVERAGE AND POPULATIONS OF INTEREST OF THE AGRICULTURAL PROGRAM AND THE INTEGRATED PROGRAM IN 50X2030



III.A. Households

The Initiative will consider, as a reference, the definition of households established by the UN World Population and Housing Census Programme 2020 (UN, 2017):

> *"the concept of household is based on the arrangements made by persons, individually or in groups, for providing themselves with food or other essentials for living. A household may be either (a) a one person household, that is to say, a person who makes provision for his or her own food or other essentials for living without combining with any other person to form part of a multi-person household, or (b) a multi-person household, that is*

to say, a group of two or more persons living together who make common provision for food or other essentials for living. The persons in the group may pool their resources and may have a common budget; they may be related or unrelated persons, or constitute a combination of persons both related and unrelated".

If national definitions differ from the UN definition, the Initiative will help countries identify the implications of using a different definition and assist them in moving towards the recommended definition.

III.B. Agricultural holdings

The definition adopted for agricultural holdings is from the FAO World Programme for the Census of Agriculture (WCA) 2020 (FAO, 2015a):

> *"Agricultural holdings are economic units of agricultural production under single management, comprising all livestock kept and all land used wholly or partly for agricultural production purposes, without regard to title, legal form or size. Single management may be exercised by an individual or household, jointly by two or more individuals or households, by a clan or tribe, or by a juridical person such as a corporation, cooperative or government agency. The holding's land may consist of one or more parcels, located in one or more separate areas or in one or more territorial or administrative divisions, providing the parcels share the same production means, such as labor, farm buildings, machinery or draught animals."*

The WCA distinguishes between two types of agricultural holding: (i) holdings in the household sector and (ii) holdings in the non-household sector.

III.B.1. Holdings in the household sector

Broadly speaking, agricultural holdings in the household sector are those operated by household members for their own account (either for sale or for their own use). In some countries, a threshold (minimum size limit) is adopted to define agricultural holdings (such as the area of agricultural land operated or number of livestock raised).

Households operating agricultural holdings for their own account are often called "agricultural production households," or simply, "agricultural households". As mentioned in the WCA, there is usually a one-to-one correspondence between an agricultural household and an agricultural holding. In other words, all the own-account agricultural production activities by members of a given agricultural household are usually undertaken under single management. It is unusual that different household members operate agricultural land or livestock independently, instead they tend to pool the income derived from these activities. Even if there is a degree of independence in their agricultural activities, the income or produce generated by different household members is usually pooled.

However, although unusual, FAO (2015a) mentions two special cases where the agricultural holding and household concepts may diverge:

- If there are two or more units making up a household, such as a married couple living in the same dwelling as their parents/in-laws, the two units may operate land independently but, as members of the same household, they make common arrangements for food and pool their incomes. In this case there is a single household but two separate holdings.

- In addition to an individual household's agricultural production activities, a household may operate land or keep livestock jointly with another household or group of households. In this case, there are two agricultural holding units associated with the household and two sets of activities: (i) the agricultural production activities of the individual household itself; and (ii) the joint agricultural operations with the other household(s).

Section VII.B discusses how to treat such cases during data collection and estimation.

III.B.2. Holdings in the non-household sector

The WCA considers the holdings of the non-household sector as agricultural holdings operated by entities such as corporations, government institutions, cooperatives, etc. A clear definition of non-household holdings as distinct from holdings in the household sector is essential because it has direct implications on the sampling design. In some contexts, confusion may arise between the household and the non-household sectors, especially with respect to households that operate large/modern commercial farms that could be classified as quasi-corporations in the System of National Accounts. Provided that business registers are among the primary sources for establishing the sampling frame for non-household holdings, FAO advises the use of such registration as a criterion for classifying quasi-corporations in the non-household sector. Therefore, holdings in the non-household sector could be considered as agricultural holdings operated by:

- Corporations as defined by the System of National Accounts.
- Government institutions (agricultural production entities operated by a central or local government directly or through a special body).
- Cooperatives.
- Institutional households such as hospitals, schools, prisons, religious institutions, etc.
- Non-profit institutions.
- Registered quasi-corporations: households with large/modern or specific agricultural operations in which income and expenditure flows from agricultural activities can be separated from other household activities, and the operations appear in the national business registry.

Corporations and government institutions may have complex structures, in which different activities are undertaken by different parts of the organization. In some cases, corporations may consist of different 'establishments' that would constitute different agricultural holdings. The WCA advises using the national accounting concept of establishment when dealing with corporations in the listing of non-household farms, whereby an establishment is an economic unit engaged in one main productive activity, operating in a single location (FAO, 2015a). For instance, a corporation that owns two distinct establishments in different locations would be considered as two different agricultural holdings.

III.B.3. Special farms

Some countries may have particular interest in special farms (commercial farms, large farms, modern farms, specialized farms, etc.) that could be in both the household and non-household sectors. In that framework, it would be important to develop a clear definition of these farms to be considered in sampling and estimation procedures. Estimation procedures with two overlapping frames (dual-frame sampling) are discussed in Section VII.E.

IV. Sampling Frames

A quality sampling frame is necessary for producing reliable survey estimates. In the framework of agricultural surveys, FAO (2017) mentions the following issues with sampling frames that are often faced and must be avoided:

- Under-coverage or an incomplete frame: failure to include some holdings in the sampling frame.
- Over-coverage: some units that are not agricultural holdings are included in the frame. For example, holdings that are listed in the frame but no longer exist.
- Multiplicity: some holdings are duplicated, increasing the likelihood of their inclusion in the sample.
- Clusters of elements: some holdings in the frame are, in fact, clusters of holdings rather than individual holdings. This is usually due to a misunderstanding of the holding's definition on the part of some enumerators, who may inventory two or more holdings as a single one.

Research projects on sampling frames for agricultural statistics, implemented by FAO in the framework of the Global Strategy to Improve Agricultural and Rural Statistics, highlighted the importance of using master sampling frames for cost-effectiveness, consistency and integration of agricultural statistics in countries. A master sampling frame is a frame that enables selection of different samples (including those from different sampling designs) for specific purposes: agricultural surveys, household surveys, and farm management surveys. Such a frame enables samples to be drawn for several different surveys or different rounds of the same survey, making it possible to avoid building an ad hoc frame for each survey (FAO, 2015b).

IV.A. Overview of a multiple-frame survey

Broadly speaking, a multiple-frame survey refers to surveys where two or more frames are used and independent samples are selected from each frame. Specifically, the use of two sampling frames for a sample survey is called dual frame survey. In the literature, the use of many frames in a survey is motivated by various reasons, including:

- **Absence of a frame with complete coverage of the population of interest**: there are situations in which it is difficult (or sometimes impossible for some populations) to get a frame with complete coverage. A solution is to use many frames on the same populations for improved coverage, exploiting the strengths and offsetting the weaknesses of each type of frame.

- **Production of reliable statistics on the subpopulation, or rare and hard-to-reach populations** depending on the country's interest.

Advantages associated with the use of multiple frames include (i) cost savings as a result of under-sampling expensive frames and over-sampling cheaper one (e.g., area and list frames), and (ii) having more flexibility in the survey design to better control survey costs, coverage, response rates, accuracy (use of different sampling designs for different frames; and use of different modes of data collection, e.g., face-to-face, phone, and web interviews). In the framework of an agricultural survey, this approach facilitates (i) the coverage of all agricultural holdings in both the household and non-household sectors, (ii) the use of the most suitable sampling design recommended for each type of holding, and (iii) the production of reliable statistics on special farms that countries are interested in. However, estimation procedures can be quite complex, in particular when the number of frames becomes high (typically more than three).

There are two important requirements for the use of multiple-frame surveys:

- **Completeness**: the union of all frames should provide full coverage of the target population. In this way, every element should be listed in at least one of the frames.
- **Identifiability**: for any sampled unit, it should be possible to understand whether or not it belongs to one of the frames.

When there is no overlap, estimation procedures are straightforward, as independent samples are selected from each of them for survey implementation. In the presence of overlap, methods proposed in the literature for dual-frame estimation are discussed below.

Methodological work on the sampling strategy of the Agricultural Integrated Survey (AGRIS) recommended two types of master sampling frames for integrated agricultural surveys (FAO, 2017):

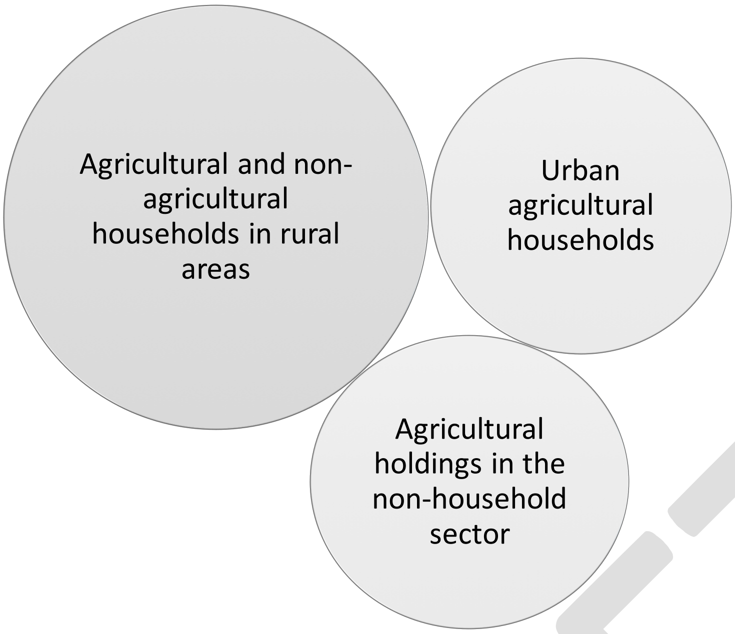
1. A multiple frame consisting in two list frames: list agricultural holdings in the (i) household sector, and (ii) non-household sector.
2. A multiple frame consisting of an area frame and the following two list frames for (i) landless holdings raising livestock, and (ii) large commercial agricultural holdings.

Both recommendations of multiple frames are valid for the Agricultural Survey Program (without the rural non-farm household sample) of the 50x2030 Initiative. However, for the Integrated Agricultural and Rural Survey Program, the first recommendation (to be combined with a frame of rural households) is the most appropriate. In fact, it complies with the need to select a representative sample of households (irrespective of agricultural engagement) in rural areas. Using an area frame will lead to an indirect sample of agricultural households with no guarantee of representativeness regarding the types of households covered (more details are provided in the section on sampling methods). However, to further improve the estimation of agricultural area and production, an area frame can be associated to the list frame of households in the multiple frame scheme.

IV.B. Frame for the Integrated Agricultural and Rural Survey Program

The frame for the Integrated Agricultural and Rural Survey Program should cover rural households (irrespective of agricultural engagement) and all agricultural holdings in the country. Accordingly, an ideal frame would include complete lists of rural households and all agricultural holdings in both the household and non-household sectors. In the household sector, agricultural holdings are generally indirectly sampled through agricultural households. This is because a direct listing of agricultural holdings poses practical challenges in most contexts as holdings may include many parcels in different locations. Therefore, a suitable master sampling frame is a multiple frame composed of (i) the list of all agricultural and non-agricultural households in rural areas; (ii) the list of urban agricultural households; and (iii) the list of agricultural holdings in the non-household sector.

FIGURE 3. SAMPLING FRAME FOR THE INTEGRATED AGRICULTURAL AND RURAL SURVEY PROGRAM



IV.B.1. Developing the frame of households (urban and rural)

A complete list of agricultural and non-agricultural households in rural areas and urban agricultural households could be established using data from a country's Population and Housing Census (PHC). However, there are potential challenges with the use of PHC data, especially in relation to the identification of agricultural households. In particular, there is a risk of over-coverage of agricultural households in urban areas if, for example, households whose members practice agriculture as paid employees are considered as agricultural households in the frame. When the PHC is implemented taking into account the United Nations Principles and Recommendations for the Population and Housing Censuses, FAO (2015b) advises that households are considered agricultural households if at least one household member's *Economic Activity Status* is that of *own-account worker*, *self-employed* or *employer*, and if their main occupation is related to agriculture (e.g., crop growing, animal production, plant propagation, or mixed farming).

However, it is very unusual to have current PHC data on hand to directly select a sample of households for survey implementation. A standard practice, where multistage sampling design is suitable (see Section V on sampling design, below), is to select a sample of primary sampling units (e.g., enumeration areas) from the PHC data and perform a fresh household listing (microcensus) in each of them, to select the final sample of households. For urban areas, it may be important to assess the suitability of a multistage sampling design before using such an approach, in particular for countries that do not have previous experience in implementing agricultural surveys. This may be performed using information from a previous PHC or agricultural census to estimate the design effect. In presence of high design effect, a simple random sampling would be more cost effective. That would require the development of an exhaustive list of agricultural urban households through a field listing operation or based on available administrative sources. Big data could be also explored (see Young et al. 2018).

IV.B.2. Coverage of urban agricultural households

The inclusion of the population of urban agricultural households is optional, depending on the importance of urban agriculture in the household sector in the country. If the incidence of urban agricultural households is particularly low, it would be cost effective to ignore these populations in data collection and consider their contribution in the estimation stage. For example, final aggregates may be adjusted using the proportions of urban agricultural households in the inference domains. In the sampling design for the 50x2030 Initiative, these populations are treated as an optional domain that countries may decide to take into account considering their importance and survey operational costs. While the proportion of agricultural households in urban areas out of all agricultural households is rather low in several countries, these households may be responsible for a large share of overall agricultural production, or the production of specific products (e.g., horticultural crops, livestock). In such cases, it will be important to consider them in the survey sample.

IV.B.3. Developing the frame of holdings in the non-household sector

The ideal situation for developing a complete list of agricultural holdings in the non-household sector would involve using data from a recent census of agriculture that covered all farms in the country. Otherwise, to build the frame for these holdings, business registers of farms are often used as a starting point, including the national business register and informal business registers held by farmers' organisations. Efforts must be made to handle the probable overlap between formal and informal registers. In addition, all other relevant registers should be considered, including the list of government institutions (agricultural research centres, schools, hospitals, prisons etc.) and non-government organisations that operate farms. Local knowledge and information from extension agents and local authorities about large specialty-type farms are useful in the process of developing the non-household sector frame. The quality of data from administrative sources mentioned above should be assessed and specific data processing operations (including record linkage) should be planned to produce a sampling frame of sufficient quality. The Word Bank's Quality Evaluation Tool for Administrative Registries would be useful for assessing the quality of these administrative records. FAO (2018c) provides practical guidance on the improvement and use of administrative data in designing agricultural surveys. Sampling frames developed from administrative sources could be further updated with complementary field operations.

IV.C. Frame for the Agricultural Survey Program

The main requirement for this frame is suitable coverage of all agricultural holdings in the country, i.e., all agricultural households and all agricultural holdings in the non-household sector. The directives discussed in Section II.A.1 for developing the frame of households can also be used for agricultural households. However, data from a recent census of agriculture may be used to develop the sampling frame for agricultural households and non-household farms, if they were covered by the census. As explained in Section II.A.1, in most cases, census data will be outdated. As a result, it would be necessary to select a sample of primary sampling units from the data in the most recent PHC or census of agriculture, followed by fresh listing operations in each of them.

Recommendations for developing a master sampling frame for integrated agricultural surveys are provided in the Handbook on the Agricultural Integrated Survey.[1] Countries are referred to these recommendations

[1] Chapter 5 of FAO (2017)

for the development of sampling frames for the Agricultural Survey Program of the 50x2030 Initiative, which has a similar structure. The two main recommendations are summarised below:

1) Build a complete list of agricultural holdings (i) in the household sector, and (ii) in the non-household sector. The list for the non-household sector can be developed as explained above in Section II.A.3. For the household sector, a cost-effective approach is to link the population and agricultural censuses as suggested by the WCA 2020 (FAO, 2015a).
2) Use a multiple frame consisting of an area frame and two list frames (landless holdings raising livestock and large commercial agricultural holdings). The operational process for building an area frame for agricultural surveys is explained in FAO (2015b). Considering that an area frame does not cover landless holdings that raise livestock, a complementary listing of these holdings is recommended. In addition, if large agricultural holdings happen to be sampled from an area frame, they may behave like outliers. A second list of large commercial agricultural holdings is therefore also recommended (FAO, 2017). Procedures for developing these lists (landless holdings and large farms) are quite similar to the ones proposed for holdings in the non-household sector (see Section III.B.3 above). The starting point would be the consultation of agricultural registers (formal and informal) in the country and other administrative sources to establish a preliminary list that should be updated with information from extension agents, local authorities and ad hoc field listing operations. Estimation approaches with overlapping sample frames are discussed in Section VII.

V. Sampling designs

The sampling strategy of the 50x2030 Initiative combines the experiences of the FAO AGRISurvey Programme and WB LSMS-ISA. Accordingly, the sampling design of the 50x2030 survey program should integrate the main features of the sampling strategies of the two survey systems.

V.A. Sampling design for the Integrated Agricultural and Rural Survey Program

The integrated sampling design should ensure reliable estimates of the main variables of interest on the populations of interest at the level of the estimation domains (also called domains of inference or analytical strata). These domains are usually administrative zones for which countries expect reliable statistics from the survey data: regions, provinces, districts, etc. The domains are country specific and the sampling design should be adapted to each of them. Countries should be advised that the choice of domains has a direct impact on the overall sample size and, accordingly, on the budget: the higher the number of estimation domains, the higher the overall budget. The sampling design for the Integrated Agricultural and Rural Survey Program is summarised in Table 1 below for the different sectors under consideration. These recommendations should be adjusted to meet country-specific needs.

TABLE 1. SUMMARY OF THE MAJOR ELEMENTS OF THE SAMPLING DESIGN FOR THE INTEGRATED PROGRAM

Items	**Populations of interest**		
	Household (rural)	**Household (urban)**	**Non-household sector**
Observation units	- Households	Agricultural holdings	Agricultural holdings

	- Agricultural holdings		
Final sampling units	Households	Households	Agricultural holdings
Frames	List of households from population census or list of EAs from population census and microcensuses in sampled EAs	List of households from population census	List of non-household farms developed from registers and/or field operations
Sampling method	Stratified two-stage	Country specific: Stratified one-stage or two-stage	Stratified one-stage
Stratification	Country specific: - PSU-level strata: administrative zones; agro-ecological zones; intensity of agricultural activity using land use data; proportion of agricultural households - SSU-level strata (intra-PSU): practice of agriculture	Country specific: administrative zones; agro-ecological zones	Country specific: administrative zones; production systems (crop/livestock/mixed); ad-hoc categorization, e.g., strata based on a measure of size (e.g., value of production)
Sampling scheme	1st stage: PPS of PSUs (EAs) 2nd stage: Systematic or Simple random sampling without replacement of Households	Country specific: depending on the sampling method adopted	Systematic or Simple random sampling without replacement within each stratum

V.A.1. Household sector (rural areas)

A standard, stratified two-stage sampling design is recommended for this sector. This sampling scheme is widely used in households and agricultural surveys. The ideal frame, as discussed above, would be the list of rural households from a recent population and housing census (PHC).

The primary sampling units (PSUs) are preferably enumeration areas (EAs) defined for the PHC because they are generally quite homogeneous in terms of population size. Homogeneity in the population will serve to improve final estimates. In some cases, it may be useful to merge some small EAs and split up big ones to improve homogeneity. FAO (2017) discusses issues related to the choice of PSU.

The PSUs should be stratified as discussed in Section VI.A. In each stratum, a sample of PSUs is drawn using a probability-proportional-to-size (PPS) without replacement sampling method.[2] The measure of the size of PSUs that are also EAs is usually equal to the number of households within that enumeration area resulting from the sampling frame.

The secondary sampling units (SSUs) are households. Within each sampled PSU, the sample of SSUs may be selected by means of stratified simple random sampling (or systematic sampling) without replacement. The stratification within the PSU is discussed in Section VI.B.

[2] Probability proportional to size is a sampling procedure whereby the probability of selection of each unit in the universe is proportional to its size, in this case the population or number of households.

V.A.2. Household sector (urban areas)

Given the rather low proportion of urban agricultural households in most contexts (as discussed above), a stratified simple random sampling would be suitable for these populations in most countries. In most cases, that operation would be cost effective if the recommended frame (the list of households from the population census) is recent, allowing a direct selection of households without making a fresh listing in the field. In any case, a relatively high geographical dispersion of the sample should be expected and that would increase the cost of data collection. If the total number of urban agricultural households is relatively important, and depending on the repartition of these households in the urban area, a stratified two-stage sampling may be explored.

V.A.3. Non-household sector

A stratified one-stage design is appropriate for holdings in the non-household sector (FAO, 2017). The stratification criteria may be the kind of agricultural production system (crop/livestock/mixed) or other ad-hoc typology. The size of the holdings, if available in the frame, could be considered for stratification or even a probability-proportional-to-size selection. Sometimes even a 'take-all' stratum might be considered to make sure that very large or special holdings are included in the survey.

V.B. Sampling design for the Agricultural Survey Program

The main difference between the Agricultural Survey Program and the Integrated Agricultural and Rural Survey Program is the exclusion of non-agricultural households in rural areas. The Agricultural Survey Program covers the same populations of interest as FAO's Agricultural Integrated Survey (AGRIS) Program. Two types of master sampling frames proposed in FAO (2017) could be used in this framework: either a multiple frame of list frames or a multiple frame of the area frame and list frame. The basic features of the sampling designs for each type of frame, discussed in detail in FAO (2017), are presented in Table 2, below. Further customization could be needed depending on country-specific situations.

TABLE 2. SUMMARY OF THE MAJOR ELEMENTS OF THE SAMPLING DESIGN FOR THE AGRICULTURAL SURVEY PROGRAM

Type of frame	Multiple frame of list frames		Multiple frame of area frame and list frame	
Sub-frame	Holdings in the household sector	Holdings in the non-household sector	Area frame	Lists
Observation units	Agricultural holdings	Agricultural holdings	Agricultural holdings	Agricultural holdings
Sampling units	Agricultural households	Agricultural holdings	Segments or points	-Landless agricultural holdings raising livestock; -Large commercial holdings
Sampling method	Stratified two-stage	Stratified one-stage	Country specific: (i) Stratified cluster sampling, or (ii) Stratified two-stage	Stratified one-stage
Stratification	Country specific: administrative zones; agro-ecological zones; intensity of agricultural activity using land use data	Country specific: administrative zones; production systems (crop/livestock/mixed); ad-hoc categorization, e.g., strata based on a measure of size (e.g., value of production)	Land cover/use	Ad-hoc categorization (e.g., based on size, activities)
Sampling scheme	1st stage: PPS of PSUs (EAs); 2nd stage: simple random sampling without replacement of agricultural households	Simple random sampling without replacement of agricultural holdings	Country specific: (i) PPS selection of segments and full coverage of all farms in the selected segments, or (ii) two stage sampling: 1st stage: PPS of PSUs (segments or grids/clusters of points); 2nd stage: Systematic or Simple random sampling without replacement of segments or points	Systematic or Simple random sampling without replacement of agricultural holdings

VI. Sample size

Calculating the sample size is a critical step in the survey design. It ensures the production of reliable statistics by keeping the sampling error to the minimum possible. The recommended approach is one that considers the analytical requirements of the survey, i.e., it ensures the reliable estimation of key variables of interest. The variable of interest can be chosen among the key variables necessary for the calculation of the most important indicators expected from the survey operation.

A measure of statistical dispersion (coefficient of variation, variance, standard error, etc.) of the variable of interest in the population is required in the sample size formula. Ideally, it is calculated using census data, but this is not always possible given the limited scope of census questionnaires. A common alternative is to estimate it from data collected in previous surveys. The measure of statistical dispersion of any variable strongly correlated to the variable of interest may also be used. Suggestions of key variables of interest are proposed in Table 3, below, considering the measurement objectives of Initiative (see Section II) and the recommended sampling frames.

TABLE 3. VARIABLES OF INTEREST SUGGESTED FOR DETERMINING SAMPLE SIZE

Sampling units	Variables of interest suggested for determining sample size
Households (agricultural and non-agricultural)	Income Agricultural area Agricultural (crop/livestock) production value
Agricultural holding in the non-household sector	Agricultural area Agricultural (crop/livestock) production value
Landless livestock holdings	Livestock production value Livestock size unit
Large agricultural holdings	Agricultural area
Segments/points (area frame)	Agricultural area

In case there are many variables of interest, the maximum of the minimum sample sizes required for each of them can be considered. This is what is proposed in Section VI.A.1, below, for the sample size of households in the Integrated Agricultural and Rural Survey Program.

If the key variable of interest is very heterogeneous in the population, the required sample size will be very large and may be unaffordable. In such a situation, the solution would be to consider the maximum sample size that the budget can support. Of course, that would not guarantee reliable estimation but the use of advanced statistical methods for optimal stratification and allocation may be helpful, for example, the optimal multivariate stratification and allocation procedures proposed by Barcaroli et al (2020) through the R Package, 'SamplingStrata'. Another alternative may be the 'stratbr' R package, described in Brito et al (2019).

VI.A. Sample size for the household sector

For this sector, a stratified two-stage sampling design is recommended. The primary sampling units (PSU) recommended are usually the enumeration areas and the secondary sampling units (SSU) are either households (Integrated Agricultural and Rural Survey Program) or agricultural households (Agricultural Survey Program). Approaches for calculating the sizes of both samples of PSU and SSU are discussed in this section.

VI.A.1. Number of secondary sampling units

Integrated Agricultural and Rural Survey Program

In rural areas, the Integrated Agricultural and Rural Survey Program has two main estimation goals: producing estimates for the whole population of rural households, and estimates for the subset of agricultural households at the national and sub-national level. To meet these objectives, the optimal sampling strategy would require a complete list of rural households from a recent PHC, classed according to whether they are agricultural (denoted as A from now on) or non-agricultural (denoted as B).

In the integrated survey, the household-sector sample size should ensure reliable estimation of a key household-related variable (e.g., income) in the population of rural households (A and B), and reliable estimation of a key agricultural variable (e.g., agricultural area) from the sub-population of agricultural households (A) as households in subpopulation B do not operate agricultural land. To calculate the minimum sample size of households needed to fulfil this goal, the usual approximate formula based on the coefficient of variation can be used.

Let us consider for each estimation domain U_d:

- M_{Ad} and M_{Bd} is the total number of households respectively of type A and B.
- cv^2_{Aincd} and cv^2_{Bincd} is the coefficient of variation of income of households of type A and B, respectively
- cv^2_{Aland} is the coefficient of variation of agricultural area of the agricultural household
- cv^{*2}_d is the maximum acceptable relative error for estimating the total (average) income and agricultural area
- $\widetilde{deff}_{Aincd}$, $\widetilde{deff}_{Bincd}$ and $\widetilde{deff}_{land}$ are estimates of the design effect for income of households of type A and B and agricultural area, respectively
- g is the expected response rate

The minimum sample size of households (m_d) in the domain U_d is:

$$m_d = \frac{1}{g}[Max\left(\widetilde{deff}_{land}\frac{cv^2_{Aland}}{cv^{*2}_d + \frac{cv^2_{Aland}}{M_{Ad}}}, \widetilde{deff}_{Aincd}\frac{cv^2_{Aincd}}{cv^{*2}_d + \frac{cv^2_{Aincd}}{M_{Ad}}}\right) + \widetilde{deff}_{Bincd}\frac{cv^2_{Bincd}}{cv^{*2}_d + \frac{cv^2_{Bincd}}{M_{Bd}}}]$$

Or:

$$m_d = \max(m_{dA,inc}, m_{dA,land}) + m_{dB,inc} = m_{dA} + m_{dB,inc}$$

This procedure requires having all the variables in the formula for household types A and B (agricultural and non-agricultural rural households) in each domain *d*. However, it may happen that the coefficient of variation of the income cannot be estimated for each subpopulation if the exercise is undertaken with data from a household survey that did not cover agricultural activities. In such case, if $m_{d,inc}$ is the overall minimum size of rural households for a reliable estimate of the income, we have:

$$m_{d,inc} = \frac{1}{g}\widetilde{deff}_{incd}\frac{cv^2_{incd}}{cv^{*2}_d + \frac{cv^2_{incd}}{M_{Ad} + M_{Bd}}}$$

And:

$$m_d = \max(\widetilde{W}_{Ad}m_{d,inc}, m_{d,land}) + (1-\widetilde{W}_{Ad})m_{d,inc}$$

Where:

- cv^2_{incd} is the coefficient of variation of the income of rural households in the domain *d*
- $\widetilde{deff}_{incd}$ is an estimate of the design effect for the income of rural households
- $\widetilde{W}_{Ad}$ is an estimate of the proportion of agricultural households in the domain *d*.

For this program, being interested only in agricultural households (A), the sample size will simply be:

$$m_d = \frac{1}{g}\widetilde{deff}_{land}\frac{cv_{Aland}^2}{cv_d^{*2} + \frac{cv_{Aland}^2}{M_{Ad}}}$$

VI.A.2. Number of PSUs

When PSUs are selected using the probability-proportional-to-size sampling method, selecting a fixed number of m_0 households per PSU will allow for constant weights. This means the number of PSUs to be selected in *d* would be given by dividing the sample size of households by m_0. With this approach, the number of PSUs to be selected in the domain *d* is given by:

$$n_d = \left[\frac{m_d}{m_0}\right] + 1$$

where $\left[\frac{m_d}{m_0}\right]$ is the integer part.

The value of m_0 can be determined considering both the costs and homogeneity of households in the PSUs (intraclass correlation $\bar{\rho}$):

$$m_0 = \sqrt{\frac{c_p \times (1-\bar{\rho})}{c \times \bar{\rho}}}$$

where c_p and c are respectively the cost of adding an additional PSU into the sample and the unit cost of an interview. The intraclass correlation $\bar{\rho}$ can be estimated from previous surveys; since two variables are considered, income and agricultural land area, the minimum value, $\bar{\rho} = min(\bar{\rho}_{cons}, \bar{\rho}_{land})$, should be considered (it is a conservative choice). It is worth noting that this formula is an approximation based on two-stage simple random sampling of both PSUs and SSUs, where the size of PSUs does not vary greatly.

Alternatively, a common practice to facilitate the organization of fieldwork consists of fixing the number of households m_0 to select in each PSU, considering the maximum enumerator workload during survey implementation. An arbitrary value generally varying between 10 and 15 is often considered.

VI.B. Sample size for the non-household sector and special farms

The sampling design recommended for agricultural holdings in the non-household sector is stratified simple random sampling. The same design is advised for complementary lists of special farms recommended in some cases (see Section IV) to improve the coverage of the sampling frames to include, for example, landless agricultural holdings raising livestock or large commercial holdings. For these populations, the agricultural production value would be a suitable variable to be considered for sample size calculations. However, for agricultural area and livestock size units, it may also be suitable to calculate the size of the sample for large holdings and landless livestock holdings, respectively.

Let us consider for each estimation domain U_d:

- M_d is the total number of holdings
- cv_{yd} is the coefficient of variation of the key variable of interest
- cv_d^* is the maximum acceptable error

- g is the expected response rate

The sample size m_d can be calculated using the following formula:

$$m_d = \frac{1}{g} \frac{cv_{yd}^2}{cv_d^{*2} + \frac{cv_{yd}^2}{M_d}}$$

VII. Stratification

Stratification consists of dividing the population into subpopulations (strata) and performing independent sample selection in each of them. Stratification can contribute to a great extent to decreasing sampling errors, particularly when subpopulations are homogeneous and if the sample size is well allocated in the strata. Other important advantages of stratification include the control of sample sizes for different subpopulations for reporting and analysis purposes, and the possibility of adopting different sampling strategies for each stratum. In many countries, households and agricultural surveys are expected to produce reliable estimates at subnational levels (regions, provinces, districts, etc.) that are the estimation domains or analytical strata. To improve estimation in the estimation domains, additional stratification, discussed here, is usually performed within them. Discussion is focused on stratification in the framework of a two-stage design with a list frame, as stratification procedures are quite straightforward with area frames and in contexts where a stratified single-stage sampling design is recommended.

VII.A. Stratification and allocation of PSUs

When implementing two-stage sampling, FAO (2017) recommends a stratification of the EAs by administrative zones (e.g., regions, provinces, etc.) and agro-ecological zones. This should happen prior to the first-stage selection, in order to improve the estimates of agricultural statistics. Stratification of PSUs should be carefully controlled, since having too many strata is not desirable (an independent sample has to be selected in each stratum). To avoid too many strata, explicit stratification can be coupled with implicit stratification. This consists of sorting the sampling frame by relevant criteria (usually geographical) in each stratum and selecting an independent sample in each stratum with systematic sampling.

Stratification in the Integrated Agricultural and Rural Survey Program

When the list of households from the PHC is outdated, the actual structure of the households within the sampled PSUs can be known only after a fresh listing of households in these PSUs. A major drawback is the lack of control over the final sample, especially the number of agricultural households required in the domain. Since the selection is made at the level of PSUs, it may show a varying situation in terms of the proportion of agricultural households.

To maintain control of the final sample size by household type (A and B), it is preferable to make a first-level stratification of the EAs in terms of the proportion of agricultural households in each of them, estimated from the latest PHC or other suitable source. Even if the PHC data is considered outdated, this structural information (proportion of agricultural households) is not likely to vary much in all PSUs and could be helpful for stratification purposes. The first-level stratification below may be considered using a proportion threshold ρ $(\frac{1}{2} < \rho < 1)$.

First-level PSU strata	Definition
Agricultural	$Proportion\ of\ agricultural\ households\ in\ the\ PSU\ \geq\ \rho$
Mixed	$1-\rho<\ Proportion\ of\ agricultural\ households\ in\ the\ PSU\ <\rho$
Non-agricultural	$Proportion\ of\ agricultural\ households\ in\ the\ PSU\ \leq\ 1-\rho$

The sample of PSUs in the domain d (n_d) can be allocated using parameters θ_a, θ_m and θ_{na} with $\theta_a + \theta_m + \theta_{na} = 1$

First-level allocation	
First-level PSU strata	**Allocation of the sample of PSU**
Agricultural	$\theta_a n_d$
Mixed	$\theta_m n_d$
Non-agricultural	$\theta_{na} n_d$

If m_0 households will be selected in each sampled PSU using a systematic or simple random sampling without replacement, the expected number of agricultural households in the final sample (m_{dAexp}) is:

$$m_{dAexp} = \rho m_0 \theta_a n_d + (1-\rho) m_0 \theta_m n_d + \delta m_0 \theta_{na} n_d = (\rho\theta_a + (1-\rho)\theta_m) m_0 n_d + \delta\theta_{na} m_0 n_d$$

$\delta < 1$ is unknown before the selection of the sample of households, contrary to the other parameters that are fixed by the sample designer.

Let us consider τ the proportion of agricultural households in the planned sample:

$$\tau = \frac{m_{dA}}{m_d} = \frac{m_{dA}}{m_0 n_d} \Longrightarrow m_{dA} = \tau m_0 n_d$$

To ensure the achievement of the planned sample of agricultural households in the final sample of households, parameters θ_a, θ_m and θ_{na} could be fixed to have $m_{dAexp} \geq m_{dA}$. That corresponds to:

$$(\rho\theta_a + (1-\rho)\theta_m) m_0 n_d + \delta\theta_{na} m_0 n_d \geq \tau m_0 n_d$$

δ being unknown, parameters θ_a, θ_m and θ_{na} can therefore be fixed under the following conditions:

$$\rho\theta_a + (1-\rho)\theta_m \geq \tau$$

$$\theta_{na} = 1 - (\theta_a + \theta_m)$$

A second-level stratification of PSUs may be performed inside the first-level strata. Common stratification criteria for improving estimates in agricultural and household surveys are: agro-ecological zones; land use classes; size categories based on population; agricultural area; intensity of agricultural activity, etc.). For countries with a strong interest in gender-disaggregated statistics, a classification of PSUs based on the number of female-headed households can be considered for stratification. The allocation in these second-level strata can follow different criteria. Typically, in household surveys an allocation proportional to the population in the strata is considered. FAO (2017) recommends the Neyman's optimum allocation for agricultural surveys. Kish (1987, page 228) suggests a compromise solution between equal and proportional allocation:

$$n_{dh} = n_d \times \frac{\theta_{dh}}{\sum_{h=1}^{H_d} \theta_{dh}}$$

Where:

$$\theta_{dh} = \sqrt{\left(W_{dh}^2 + \frac{1}{H_d^2}\right)}$$

H_d is the number of strata in the domain d, while W_{dh} is the relative size of stratum h in domain d, it can be the proportion of PSUs in stratum h compared to the domain total, $W_{dh} = N_{dh}/N_d$, (relative size in terms of population). A multivariate stratification and allocation (Barcaroli, 2020) or compromise power allocation (Bankier, 1988) could also be explored if the frame contains relevant variables correlated with households' income or agricultural area (household size, livestock, agricultural production, etc.) at PSU level.

Stratification in the Agricultural Survey Program

In the context of the Agricultural Survey Program, the same PSU stratification strategy proposed above could be used, but the first-level allocation is not necessary as this survey program does not cover non-agricultural households.

VII.B. Intra-PSU stratification and allocation

Although intra-PSU stratification has a limited effect on the total variance, it can be helpful to ensure good coverage of specific populations of interest. For the Integrated Agricultural and Rural Survey Program, a relevant stratification criterion could be whether agriculture is practiced or not. Countries interested in gender-disaggregated statistics may also consider the gender of the head of the household. For the Agricultural Survey Program, production systems (crop/livestock/mixed) should be explored if such information is available in the frame. A proportional allocation of the sample should be used in the PSU to ensure the final units have equal probability of selection in the PSU. Alternatively, an implicit stratification could be considered, i.e., ordering households by type and subsequent selection of the random sample of m_0 by means of systematic criterion.

VIII. Estimation

Estimators, variances and specific issues related to estimation are discussed in this section.

VIII.A. Estimators and variances

The main estimators and variances from the sampling schemes proposed are presented here.

VIII.A.1. Stratified two-stage sampling design

Notation

h = stratum

H = total number of strata

i = PSU

N = total number of PSUs

I_h= total number of PSUs in the h^{th} stratum

j = SSU

M_{hi}= total number of SSUs found in the *i*-th PSU in stratum *r* ($j = 1, 2, \dots, M_{hi}$)

$M = \sum_h \sum_i M_{hi}$= total number of SSUs in the country

F_{hi}= total number of SSUs listed in the sampling frame as belonging to the *i*-th PSU in stratum *h*

$F_h = \sum_i F_{hi}$, is the total number of SSUs listed in the sampling frame in stratum *h*

n_h= number of sample PSUs selected in stratum *h*

m_{hi}= number of sample SSUs selected in *i*-th PSU in stratum *h*

y_{hij}= value of the target variable *Y* observed on the *j*-th SSU, in *i*-th PSU in stratum *h*

Estimators

The probability of selecting the SSU *j* in the sample is the product of the probability of selection of the PSU *i* in which it is located ($n_h \frac{F_{hi}}{F_h}$) and its probability of selection in the PSU *i* ($\frac{m_{hi}}{M_{hi}}$).

Thus, the *weight* assigned to the SSU f selected in the *i*-th PSU in stratum *h* is:

$$w_{hij} = \left(n_h \frac{F_{hi}}{F_h}\right) * \left(\frac{M_{hi}}{m_{hi}}\right)$$

The weights are roughly constant within each stratum when m_{hi} is constant ($m_{hi} = m_{h0}$) and when the number of SSUs found in a sampled PSU is approximately equal to the number of SSUs resulting from the sampling frame ($M_{hi} = F_{hi}$).

An estimate of the total amount of Y for the entire population may be computed with the following formula:

$$\hat{Y} = \sum_h \sum_i \sum_j w_{hij} y_{hij}$$

The mean of Y can be estimated with two different estimators:

- *Simple mean*

$$\hat{\bar{Y}} = \hat{Y}/M$$

- *Weighted sample mean*

$$\tilde{\bar{Y}} = \frac{\hat{Y}}{\sum_h \sum_i \sum_j w_{hij}}$$

This latter estimator tends to be preferable to the simple mean when the total size of the population is unknown or uncertain (as occurs, for example, if the frame is obsolete) and when estimating the mean of *Y* for an unplanned domain of interest (e.g., subpopulation).

Variance

The variance of the estimator of the total amount *Y* in the population is a rather complex formula and can be found, for instance, in Cochran (1977, equation 11.42). A simple approximate estimation of such a variance involving the PSUs alone can be obtained with the following estimator, provided by Särndal, Swensson, and Wretman (1992, p. 154), which overestimates this variance

$$\tilde{V}(\hat{Y}) = \sum_{h=1}^{H} ({M_h}^2 \frac{1}{m_h(m_h-1)} \sum_{i=1}^{I_h} (\hat{Y}_{hi} - \frac{1}{m_h} \sum_{i=1}^{I_h} \hat{Y}_{hi})^2)$$

where $\hat{Y}_{hi}$ and $\hat{Y}_h$ are the estimates of the total amount of *Y* at the? PSU and stratum levels, respectively.

An approximate estimator of the variance of the mean is:

$$\tilde{V}\left(\hat{\hat{Y}}\right) = \frac{1}{M^2} \tilde{V}(\hat{Y})$$

Coefficient of variation of the total:

$$\widetilde{CV}(\hat{Y}) = \frac{\sqrt{\tilde{V}(\hat{Y})}}{\hat{Y}}$$

Coefficient of variation of the mean:

$$\widetilde{CV}\left(\hat{\hat{Y}}\right) = \frac{\sqrt{\tilde{V}\left(\hat{\hat{Y}}\right)}}{\hat{\hat{Y}}}$$

VIII.A.2. Stratified one-stage sampling design

Let us consider the following notation:

h = stratum

H = total number of strata

i = agricultural holding

N_h= total number of agricultural holdings in stratum *h*

N = total number of agricultural holdings in the frame

n_h= number of sample agricultural holdings selected in stratum *h*

y_{hi} = value of the target variable Y observed on the *i*-th agricultural holding, in stratum *h*

The weight of the *i*-th agricultural holding in stratum *h* is simply the inverse of its probability of selection:

$$w_{hi} = \frac{N_h}{n_h}$$

An estimate of the total amount of *Y* for the population of agricultural holdings is:

$$\hat{Y} = \sum_h \sum_i w_{hi} y_{hi}$$

An estimate of the sampling variance is provided by:

$$\tilde{V}(\hat{Y}) = \sum_{h=1}^{H} N_h(N_h - n_h) \frac{1}{n_h(n_h - 1)} \sum_{i=1}^{n_h} (y_{hi} - \overline{y_h})^2$$

Where:

$$\overline{y_h} = \frac{1}{n_h} \sum_{i=1}^{n_h} y_{hi}$$

An estimate of the population mean of *Y* is provided by:

$$\hat{\bar{Y}} = \hat{Y}/N$$

And the corresponding sampling variance is estimated through:

$$\tilde{V}\left(\hat{\bar{Y}}\right) = \frac{1}{N^2} \tilde{V}(\hat{Y})$$

The coefficient of variation of the total and the mean can be estimated using the same formulas provided for the stratified two-stage sampling design.

VIII.B. Issue of difference between sampling and observation units in the household sector

The sampling unit proposed for the survey programs in the household sector is the household. However, the observation unit for the agricultural component is the agricultural holding. Therefore, it is important to discuss the relationship between households and holdings to be considered in computing the sampling weights of the holdings. Four types of links are expected between observation and sampling units (Lessler and Kalsbeek, 1992). In the framework of integrated surveys, they can be described as follows:

- One-to-one: each household is associated with a unique agricultural holding and each agricultural holding is associated with a unique household.
- One-to-many: one household can be associated with many agricultural holdings, but each agricultural holding is associated with only one household.
- Many-to-one: many households can be associated with one agricultural holding, but each household is associated with only one agricultural holding.
- Many-to-many: each agricultural holding may be associated with many households and each household may be associated with many agricultural holdings.

The number of sampling units that would lead to the collection of data from the same reporting unit is referred to as "multiplicity" (FAO, 2015b). Here, multiplicity arises when an agricultural holding is operated by two distinct households or more, or when a single household operates two or more distinct holdings. In the household-sector, the latter case is very rare, and it is operationally complex to capture in the survey considering the definition of the holding. Acknowledging the rarity of this situation and the complexity of treating the holdings present in the household as two separate entities, the 50x2030 survey instruments collect the information as if the holdings were a unique entity.

The existence of multiplicities leads to biased estimates (Lavalée, 2007). Falorsi et al. (2015) recommend using the Generalized Weight Share Method (GWSM), proposed by (Lavalée, 2007), when dealing with multiplicities between holdings and households.

The following operational recommendations can be made for the use of the GWSM in the framework of the 50x2030 integrated sampling design:

(i). Identifying multiplicities during household listing: when listing households in the PSU, include questions to identify multiple-household holdings.
(ii). After sampling and during the actual survey, identify the sampled households linked to each multiple household-holding.
(iii). During data processing, compute sampling weights of the multiple-household holdings using the Generalized Weight Share Method.

Let us consider:

w_i the sampling weight of the household i ($w_i = 0$ if the household is not sampled)

$l_{ij} = 1$ if the household i operates the agricultural holding j and $l_{ij} = 0$ otherwise

The sampling weight $w_j{}'$ of the agricultural holding j can be expressed as:

$$w_j{}' = \frac{\sum_i l_{ij} w_i}{\sum_i l_{ij}}$$

VIII.C. Weighting using different observation units

To fulfil the main objectives of the Initiative, two observation units are considered: households and agricultural holdings. However, as indicated above, there is evidence of the existence of multiple-household holdings and they should be identified in the sampling frame. In countries where there are many cases of households operating agricultural holdings in partnership, given the requirement of collecting data at both household and holding levels, the following actions should be taken:

- Identify agricultural information that should be captured at both household and holding levels, including revenues and expenses, assets, investments, etc.
- When interviewing households operating a multiple-household holding, collect this information separately at the household level and the holding level. Obviously, this will increase the interview burden for these respondents but hopefully, as mentioned below, such cases will be unusual.
- Finally:
  - weighted estimation of household-level data at the national level will be calculated using households' direct sampling weights as design weights. Design weights are then adjusted through calibration, post-stratification, non-response adjustments etc., to calculate the final weights.
  - weighted estimation of holding-level data at the national level will be done using the holdings' sampling weights ($w_j{}'$) calculated as explained in the previous section and using the final weights of households.

Therefore, final household and holding weights will be different only in the case of holdings operated by more than one household.

VIII.D. Estimation for rare crops

Covering rare items is a challenge in all surveys as it could require a very large sample. With the 50x2030 survey methodology, reliable estimation for most crops should be possible at the national level but not for subnational domains. For very rare crops, there is no such guarantee even at the national level, but upon country request, advanced estimation approaches (e.g., small area estimation models) could be explored using available auxiliary information from administrative data or previous agricultural censuses. Such auxiliary information could be also used at the design stage to explore ad-hoc stratification to improve the coverage of rare crops for reliable estimates.

IX. Subsampling and estimation

In agricultural and household surveys, subsampling can be used as a cost-effective tool for various purposes including the following.

Use of different estimation domains for specific information

If the main domains of the survey are, as usual, subnational administrative areas (regions, provinces, districts etc.), the country could consider that some information is only necessary for estimation at the national level. Therefore, it will not be necessary to collect it in the full sample in each estimation domain. The sample size for country-level estimation can be calculated for this information and the corresponding questions will be administered only to a subsample in each estimation domain. For instance, if most information collected by a rotating module is not requested for subnational policy making, the rotating questionnaires could be administered to a subsample.

Collecting information with higher operational cost and/or time requirements

Some data collection methods provide high-quality information, but their implementation may be too expensive to implement at full scale, for example, objective measurements of land (e.g., using GPS) or yield (crop cutting). Such operations may be performed on a subsample when full-scale implementation is not feasible, and the results may subsequently be used to correct measurement error for the whole sample. Successful construction of correction factors depends on the nature of the measurement error, and may not be possible in all cases.

IX.A. Subsample size

The size of the subsample can be calculated using the variability of key variables intended for collection through the subsample. One option is to stratify the main sample before selecting the subsample. In such a case, Fuller (2009) proposes a formula to calculate the optimal subsample size. For instance, let us suppose that the subsampling is performed for objective measurement of the yield and let y be the yied collected through declaration. If the sample is stratified into H strata, the optimal sample size of the subsample, following Fuller (2009), will be:

$$m_{subsample} = m\sqrt{\frac{\sigma_w^2 C_1}{\sigma_b^2 C_2}}$$

Where:

$$\sigma_w^2 = \frac{\sum_{h=1}^{H} \sigma_{yh}^2}{H}$$

$$\sigma_b^2 = \sigma_y^2 - \sigma_w^2$$

σ_y^2 and σ_{yh}^2 are the variances of y in the full sample and in the stratum h, respectively.

m is the sample size of the survey.

C_1 and C_2 are the costs of the interview by declaration and objective measurement, respectively. In case reliable information on unit costs C_1 and C_2 are not available, a proxy value of $\frac{C_1}{C_2}$ can be considered here based on expert opinions and cost simulations.

IX.B. Subsampling for specific modules/questionnaires

The 50x2030 Initiative broadly proposes a modular survey system with an annual core survey tool focused on crop, livestock, aquaculture, fishery, and forestry production (CORE-AG), and a set of specialized modules (see Section II):

- Farm Income, Labor, and Productivity (ILP)
- Production Methods and Environment (PME)
- Machinery, Equipment, and Assets (MEA)
- Non-Farm Income and Living Standards Household (ILS-HH)

These specialized modules are administered at lower frequencies and all are part of the Integrated Agricultural and Rural Survey Program. However, the ILS-HH is not administered in the Agricultural Survey Program.

As the specialized modules are generally considered for indicators and analyses that are required at the national level, it is suggested to consider them for larger estimation domains, potentially even at the national level only, instead of subnational administrative areas. For example, while the CORE-AG questionnaire may seek data representative at the district level, and potentially for specific crops, questionnaires such as the ILS-HH may be implemented with a sample representative at the regional or national level, depending on country needs. This recommendation has some advantages as it will reduce respondent burden in an important part of the sample. The reduction of interview length has a direct effect on the data collection cost and the reduction of measurement errors due to respondent burden. However, the use of a subsample in this framework may affect the precision of estimators, as estimation will be performed in a two-phase sampling scheme.

In order to improve the estimation of the total income (farm and non-farm), it is recommended to consider a unique subsample of agricultural households for both the ILS-HH and ILP modules (the same agricultural households will receive the ILS and ILP modules). As the non-agricultural households will be administered only ILS-HH module, there is obviously no need to select a subsample of these populations for the survey.

The subsample can be selected through a simple random sampling without replacement using the large sample. However, if there is relevant information on the large sample for stratification, it can be stratified before sample selection. For instance, in the framework of a two-stage sampling, information collected with the listing questionnaire in the primary sampling units may be helpful for such stratification.

IX.C. Case of crop cutting

Generating data on crop cutting is a demanding activity, but one that adds significant value to survey operations. It requires the acquisition of specific equipment and at least two visits of the enumerator of the holding (during planting and harvesting periods). Some countries, such as Niger and Burkina Faso, implement crop cutting in their agricultural survey operations on the full sample of holdings and all plots covered by the operation. However, a subsample of holdings and/or plots may be used especially when only national-level estimates of crop yields are expected from the survey or if the results of crop cutting are intended to be used for correcting yield estimates based on farmers' declarations.

Subsampling approaches

Options for subsampling for crop cutting include:

- Directly selecting a subsample of plots (bypassing the holding level) for implementing crop cutting. This is an efficient option (in terms of quality of estimation) but has some operational constraints. In fact, it can be performed only after the listing of all plots of the holdings. Therefore, this listing should be completed in a timely manner to allow the processing of the data and selection of the subsample of plots. In addition, large plots or plots very far from the holding dwelling may appear in the sample, increasing operational costs.
- Selecting a subsample of holdings and covering all or some plots of each subsampled holding by the crop cutting operation. This may allow coverage of more parcels than the previous option and at a lower cost, since the holding is a cluster of plots. However, it is less efficient than the previous option as cluster sampling leads to larger variance.

IX.D. Case of farm-level post-harvest losses

FAO discusses the main post-production operations during which harvest losses occur at different stages of the value chain (FAO, 2018c). At the farm level, in the case of grains (cereals and pulses), losses occur mainly during the following operations: harvesting; threshing or shelling; cleaning or winnowing; and drying and storage at the holding (FAO, 2018a). The Guidelines recommend using probability sample surveys as the backbone of any loss assessment, complemented by other methods that may be used mainly as preliminary assessments or to further analyze certain aspects related to post-harvest losses. With such surveys, loss measurements can be (i) objective – drawn from crop cutting in the field or laboratory analysis of grain sampled from storage facilities, or (ii) subjective - by asking the respondent (farmer, storage facility manager, etc.) to provide their own estimate of loss.

In the framework of the initiative, it is recommended to make post-harvest loss assessments using a subsample for a number of reasons, including reducing operational costs and respondent burden. In fact, both options of loss measurements (objective and subjective) are relatively expensive and time-consuming, and require well-trained personnel (FAO, 2018a). Objective measurements are particularly expensive and require many visits of the enumerators to the farm. Subjective assessments are cheaper but require additional visits to the farm in particular for collecting information on storage losses; thus, additional cost may be important. In addition, field tests performed by FAO in the framework of the Global Strategy showed important errors when comparing objective and subjective measurements in Ghana, Malawi, Namibia and Zimbabwe (FAO, 2018b).

Another reason for subsampling is that information on post-harvest losses is generally needed at the national level, meaning subnational estimation is not necessary. In addition, regarding international demand, SDG 12.3.1 on Global Food Loss Index is expected at country level.

Important indicators related to post-harvest losses are the proportions of losses at the crop and operation levels. The crop of interest should be specified, although they are generally cereals and pulses. Therefore, the subsampling should be performed among holdings producing the target crops.

IX.E. Estimation with subsampling

If subsampling is used to collect specific information, estimation can be done using (i) a three-stage sampling scheme, or (ii) a two-phase sampling scheme.

If the entire sample of holdings is covered and a subsample of plots selected in each of them, this corresponds to a three-stage sample selection. New sampling weights should be calculated for the subsampled plots by multiplying the inverse of their probability of selection and the sampling weights of the holdings. Estimators of variances provided for the two-stage design can still be used here with few adaptations.

However, selecting a subsample of holdings would correspond to a two-phase sampling. Estimation can be done using regression or ratio estimators. Regression estimators are considered more efficient in this context (Cochran, 1977). Let us consider the use of subsampling for objective measurements (GPS measurement or crop cutting) in a two-stage scheme (subsample of holdings). For simplicity, we will consider the case of a sample of holdings selected through a simple random without replacement approach, from which a simple random subsample of holdings is selected for the objective measurements. Let us consider y the yield measured using the crop cutting data in the subsample and x the yield collected by declaration on the whole sample. From Sitter (1997), the regression estimator used to estimate a more accurate average yield is:

$$\bar{y}_{reg} = \bar{y} + \beta(\bar{x} - \bar{x}_{subsample})$$

Where:

$\bar{x}_{subsample}$ is the average of x in the subsample and β the least squares regression coefficient of y on x in the subsample.

An estimator of the variance of $\bar{y}_{reg}$ is:

$$\tilde{v}(\bar{y}_{reg}) = \left(\frac{1}{m_{subsample}} - \frac{1}{m}\right)s_d^2 + (\frac{1}{m} - \frac{1}{M})s_y^2$$

Where:

- $m_{subsample}$ = size of the subsample
- m = size of the whole sample
- M = size of the population of holdings
- s_d^2 = the sample variance of the quantities $d_i = y_i - \bar{y}_i - \beta(x_i - \bar{x}_i)$

X. Coverage of special farms (commercial, large, modern, etc.) and dual-frame estimation

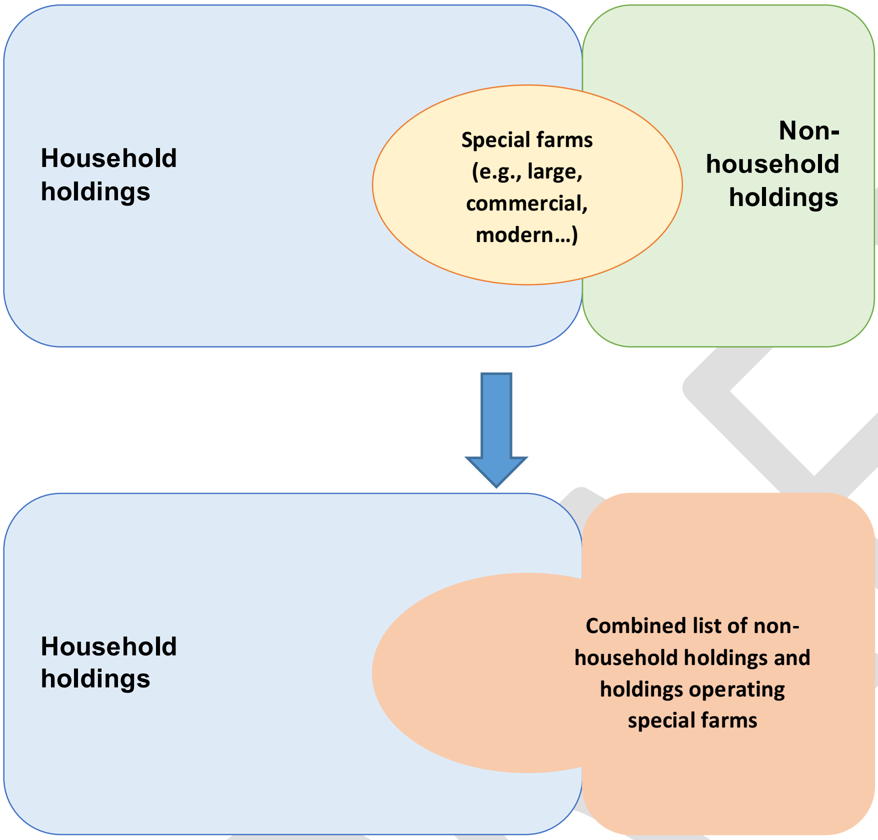
The definition adopted by the Initiative for agricultural holdings of the non-household sector (non-household holdings) allows for the avoidance of overlap of this population with the population of agricultural holdings of the household sector (household holdings). However, it usually happens that countries are interested in some special farms (e.g., commercial farms, modern farms, large farms, organic farms, farms producing specific crops, etc.) for various reasons. In particular, they need information to make decisions related to specific types of holdings or the monitoring of agricultural programs supporting those holdings. In addition, complementary lists of holdings with special farms are recommended in some cases (see Section IV), to improve the coverage of the sampling frames, such as landless agricultural holdings raising livestock or large commercial holdings. The agricultural holdings operating such special farms can belong to both the household sector and the non-household sector.

When a country has an interest in special farms, a clear definition should be elaborated and a list of special farms established through administrative data and/or listing operations as a sampling frame for them. This list will overlap with either the frame of household holdings, the frame of non-household holdings, or both, inevitably leading to a dual-frame survey.

Regarding the sampling approach of special farms, it can be observed that some countries opt for the creation of an explicit stratum of agricultural households operating special farms, after listing operations in the sample of PSUs used for the selection of household holdings. However, this approach presents some weaknesses affecting the efficiency of the sample, especially when the proportion of households operating special farms is low and/or the geographical distribution of these farms is asymmetric. This does not guarantee reliable estimation of the population of special farms as the explicit stratification is performed in a sample and may lead to an under-sampling of household holdings, affecting the precision of the estimates.

In practice, when special farms are of interest and list frames are used as sampling frames, a single list can be developed for both populations of holdings operating special farms and non-household holdings, as the same sampling design is recommended for both (stratified one-stage), and listing strategies are quite similar for both. Thus, in the end, the latter list and the list of household holdings will constitute an overlapping dual frame that will be represent the sampling frame covering all holdings and allowing the production of reliable statistics on the special farms. The overlapping units are simply household holdings operating special farms.

FIGURE 4. PROCEDURE OF FRAME DEVELOPMENT FOR COVERING SPECIAL FARMS



X.A. Screening approach

The screening estimator approach consists of removing the overlapping units, either from one frame before sample selection, or from one sample before data collection. It can be considered a special case of stratified sampling and, accordingly, estimation is straightforward. Common drawbacks of the screening approaches are that they can be resource consuming, error-prone and amount to a missed opportunity to collect data from a willing participant.

X.A.1. Frame-level screening

This screening approach consists of removing the overlap between frames (de-duplicating the frames) before the sample selection. For instance, in the case of a dual-frame survey of household holdings and special farms, the screening will consist of removing households operating special farms from the complete lists of agricultural households in the EAs before selecting the sample of agricultural households. Before such removals, it is important to ensure that the special farms screened in the EAs are included in the frame of special farms. This may increase the listing time in the EAs when the identification of special farms requires many additional questions in the listing form.

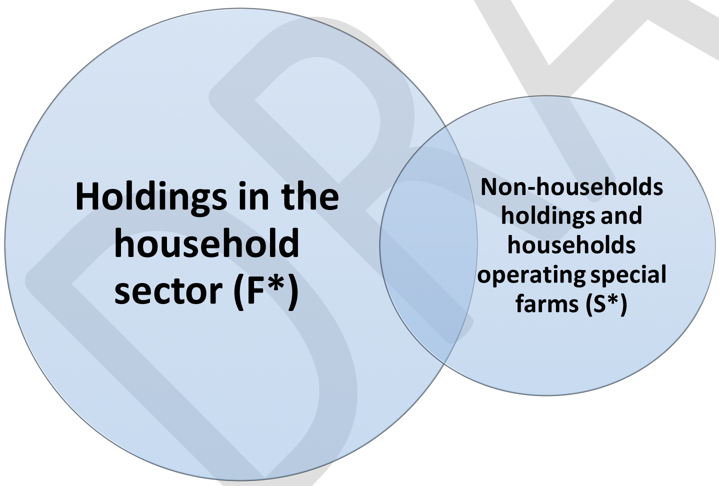
X.A.2. Sample-level screening

In this screening approach, the overlap between one frame and the sample selected from the other frame (usually the most expensive frame) is removed. For example, when a dual frame of an area and list frame is used, agricultural holdings identified in the area sample (e.g., sample of segments) are removed from the list frame before selecting the sample from the list. The sample-level screening is considered acceptable when the overlap is relatively small. A specific drawback of this approach is that it may increase non-response errors.

X.B. Dual-frame estimators

Consider a typical situation when a country is interested in special farms and is using a dual-frame consisting of a list of holdings in the household sector and a combined list of non-household holdings and households operating special farms.

FIGURE 5. ILLUSTRATION OF A DUAL FRAME COVERING AGRICULTURAL HOLDINGS AND SPECIAL FARMS



Let N be the total number of agricultural holdings in the estimation domain (or domain of inference), F^* the population of holdings in the household sector, and S^* the population of non-household holdings and households operating special farms. The population of agricultural holdings from these two frames ($F^* \cup S^*$) can be divided into three mutually-exclusive subpopulations:

F: the population of household holdings not operating special farms, with a size N_f

FS: the overlapping population of household holdings operating special farms, with a size N_{fs}

S: the population of non-household holdings with a size N_s

Therefore: $N = N_f + N_{fs} + N_s$

Let Y be a variable of interest (e.g., agricultural planted area) in the population of agricultural holdings and let y_k be its value on unit k, for $k = 1, \ldots, N$.

The objective is to estimate using the data from two independent samples surveys (households and registered farms) the population total $Y = \sum_{k=1}^{N} y_k$ that can be written as:

$$Y = Y_f + Y_{fs} + Y_s = \sum_{k=1}^{N_f} y_k + \sum_{k=1}^{N_{fs}} y_k + \sum_{k=1}^{N_s} y_k$$

The simple summation of the two totals of Y, estimated from the two samples, is biased because of the overlap between the two sampling frames used to select the samples. Different methods are proposed in the literature for estimation from dual-frame surveys. The most famous were proposed by Hartley (1962; 1974), Fuller and Burmeister (1972), Bankier (1986), Kalton and Anderson (1986), Skinner (1991), Skinner and Rao (1996), Singh and Wu (1996; 2003), Lohr and Rao (2006), Mecatti (2007), and Singh and Mecatti (2011).

Estimation in general, and variance estimation in particular, are not always straightforward in dual-frame surveys. Arcos et al., (2015) note that standard software packages for complex surveys cannot be used directly when the sample is obtained from a dual-frame survey because the classical design-based estimators are severely biased and there is an underestimation of standard errors. The authors developed the R package *Frames2* that can be used for dual-frame estimation using most of the methods mentioned above.

The dual-frame estimation method proposed by Hartley (1962) consists in weighting the two estimates of Y for the overlapping domain (here, the overlapping population FS) to avoid the overestimation bias. The Hartley's estimator is given by:

$$\hat{Y}_H = \hat{Y}_f + \theta \hat{Y}_{fs}^{f} + (1 - \theta)\hat{Y}_{fs}^{s} + \hat{Y}_s$$

Where:

- $\hat{Y}_{fs}^{f}$ is the estimator on the domain FS, based only on the data of the sample of household farms
- $\hat{Y}_{fs}^{s}$ is the estimator on the domain FS, based only on the data of the sample of non-household or special farms
- θ is an arbitrary constant, such that $0 \leq \theta \leq 1$

It can be easily noted that using $\theta = 0$ or $\theta = 1$ is equivalent to a sample-level screening approach (see Section 5.3.2.). Hartley (1974) proposed an optimal value for θ, minimising the variance of $\hat{Y}_H$:

$$\theta_{opt} = \frac{V(\hat{Y}_{fs}^{s}) + Cov(\hat{Y}_s, \hat{Y}_{fs}^{s}) - Cov(\hat{Y}_f, \hat{Y}_{fs}^{f})}{V(\hat{Y}_{fs}^{f}) + V(\hat{Y}_{fs}^{s})}$$

This optimal value can be estimated using the R package *Frames2* (Arcos et al., 2015). The main drawback is that it is variable-specific, i.e., it needs to be estimated for each indicator.

The Hartley's estimator with $\theta = {}^{1}/_{2}$ (also called average estimator) is equivalent to the multiplicity estimator proposed by Mecatti (2007) for multiple-frame surveys, and contains features that could be of interest to some countries. Lohr (2011) mentioned that the value of $\theta = {}^{1}/_{2}$ is frequently recommended with the Hartley's estimator. The average estimator may not be the most efficient in many contexts, compared to other dual-frame estimators, but it can be recommended to countries because it offers operational advantages. Firstly, it is straightforward to compute and implement because the value of θ does not depend on the quantity of interest (Baffour et al., 2016), and its variance is quite easy to estimate. In addition, it provided good results in a number of experiences in the literature, including the Brick et al. (2006) dual-frame survey of landline and cell phone numbers, and the Ferraz et al. (2017) dual-frame of area and list frames in agricultural surveys. Ferraz et al. (2017) note that the average estimator is more efficient than the screening estimator. Chauvet and Tandeau de Marsac (2014) undertook simulations comparing the performance of several dual-frame estimators in two-stage sampling designs and concluded that a simple estimator is sometimes preferable, even if it uses only part of the information collected.

Estimation is straightforward using the average (or multiplicity) estimator, which can be presented as follows:

$$\hat{Y} = \hat{Y}_f + \frac{1}{2}\hat{Y}^f_{fs} + \frac{1}{2}\hat{Y}^s_{fs} + \hat{Y}_s$$

Let us consider:

S^f and S^s the samples selected from the populations F^* and S^*, respectively

w_i^f : sampling weight of unit i selected in S^f

w_i^s: sampling weight of unit i selected in S^s

The use of the average estimator will simply consist of calculating the adjusted weight as follows:

$$w_i^{*f} = \begin{cases} w_i^f \, if \; i \in F \\ \frac{1}{2} w_i^f \, if \; i \in FS \end{cases}$$

$$w_i^{*s} = \begin{cases} w_i^s if \; i \in S \\ \frac{1}{2} w_i^s if \; i \in FS \end{cases}$$

Adjusted weights should be used for estimation on the population of agricultural holdings (e.g., area, production, etc.) using the standard Horvitz-Thompson estimator. However, the initial weights w_i^f and w_i^s are kept in the two samples to be used for estimations specific to populations F and S, respectively. For instance, the estimation of the production of special farms would be performed using the sample S^s and the initial weights w_i^s.

Given that samples were selected independently from the two frames, the variance estimation is straightforward using any standard statistical software: $V(\hat{Y}) = V(\hat{Y}_{hf} + \frac{1}{2}\hat{Y}^{hf}_{hfr}) + V(\frac{1}{2}\hat{Y}^{r}_{hfr} + \hat{Y}_r)$.

XI. Longitudinal data collection scheme and tracking procedures

The 50x2030 survey programs recommend annual data collection on the agricultural sector. From one year to another, there are three alternatives regarding the samples for such repeated surveys: (i) selecting a new sample every year (often called "repeated cross-section"); (ii) using the same sample during a number of years (panel); and (iii) changing a proportion of the sample from one year to another (partial rotation).

The panel approach generally presents lower operational costs as the same sample is surveyed every year over a period of time, especially for surveys that do not require intensive tracking operations. The panel is also well suited to estimating change but the panel sample may not be representative after a number of years because of sample attrition and structural changes in the population.

The partial rotation scheme is therefore a good alternative, especially for a survey plan with a relatively long period of implementation, although it could also suffer from sample attrition. It is less expensive than the repeated cross-section approach, and allows longitudinal analyses and facilitates more precise estimates of the changes.

The first option would improve annual cross-sectional estimates if the sampling frame is fully updated every year prior to sample selection. However, compared to the other options, it will place higher operational costs on the survey program, including annual costs for updating the sampling frame and locating the sampling units for survey implementation. In addition, because there is no or little overlap between successive samples, repeated cross-sections usually present more discrepancies in time series data, estimates of changes are less precise and longitudinal analyses are very limited and sometimes impossible.

For the 50x2030 Initiative, the panel and the partial rotation approaches are advised as cost-effective sampling approaches over time. In countries where the rate of unit non-responses is usually high (as observed in previous surveys), the panel approach should be avoided because of the risk of high non-response rates over time, due to respondent burden.

TABLE 4. PROS AND CONS OF SAMPLING APPROACHES OVER TIME

Approach	Pros	cons
Repeated cross-sections	▪ Better sample representativeness (updated frame and sample) ▪ More precise cross-sectional estimates	▪ High annual operational costs: update of the frame, new sample to be interviewed ▪ Less precise estimates of change/ longitudinal studies not feasible ▪ May need data reconciliation from one year to another
Panel	▪ Reduce the variation of the estimates ▪ Precise estimates of change ▪ Smoother time series data ▪ Low operation cost (in case without heavy tracking)	▪ Low sample representativeness if there are important structural changes in the population ▪ Sample attrition: respondent burden, change or movement of units
Rotation	Compared to repeated cross-sections: ▪ Improved precision of estimates of change ▪ Lower operation cost	▪ Affects sample representativeness depending on sample fraction

XI.A. Length of panel/rotation design

For the Integrated Agricultural and Rural Survey Program, a three-year panel or rotation would be cost effective because non-agricultural households are considered every three years in that survey program. For the Agricultural Survey Program, there is more flexibility in the choice of the length of the panel/rotation.

However, as the efficiency of the panel/rotation sample will decrease over time, it is important to avoid lengthy periods for the panel/rotation. Three to five years would be suitable, depending on specific country contexts.

XI.B. Handling sample attrition

Attrition in a repeated survey is the dropout of sample units from one survey round to another. Both panel and rotating samples could suffer from attrition bias. Attrition affects both cross-sectional and longitudinal estimates because of the reduction of sample size and potential systematic nature of the attrited units. Attrition bias is usually well addressed with weight adjustments for cross-sectional estimation when the attrition rate is not very high, but estimates of longitudinal changes are definitively less precise in the presence of attrition. Therefore, it is best to develop strategies to avoid this issue as much as possible.

There are a number of approaches in the literature to handling sample attrition, including sensitizing, giving incentives to respondents, replacement, oversampling, tracking, and follow-up interviews. In the framework of the 50x2030 Initiative, replacements are not advised because of selection bias issues (Witoelar, 2011). Oversampling and tracking approaches, explained below, are widely used solutions.

However, in the presence of high attrition, it would be suitable to update the sample in the successive survey round. In fact, the adoption of panel/rotation design implicitly supposes that significant change in the population of interest is not expected in the very short term (one to three years). Such an assumption would not hold if high attrition is recorded.

XI.B.1. Oversampling

Oversampling is a way of anticipating attrition by increasing the sample size accordingly. It can be performed by multiplying the sample size by the inverse of the expected response rate. Response rates from previous survey rounds or similar surveys in the country are generally considered. That attenuates the effect of attrition on sampling error, due to the smaller sample size. To completely avoid unit non-responses during the first survey round, an "inverse sampling" approach could be adopted. Broadly speaking, this refers to a scheme in which units are selected successively until a predetermined number of units with a certain characteristic is obtained (Tillé, 2016). In order to maximize the response rate, an application of inverse sampling consists in selecting a larger sample and performing interviews until the target number of valid interviews is reached (Vasconcellos et al., 2005). This provides options for a more targeted effort, when compared to broad oversampling carried out beforehand.

XI.B.2. Tracking

In longitudinal surveys, tracking refers to following and interviewing respondents who move from the location where they were first interviewed. Tracking procedures aim to address not only the issue of missing units but also issues related to important changes in the observation units. Tracking in the framework of the 50x2030 Initiative concerns agricultural holdings (i.e., agricultural households and holdings in the non-household sector).

a) When to track?

When deciding on conditions for tracking, it is important to consider the objectives of the survey (Witoelar, 2011). In the framework of agricultural surveys, tracking of agricultural holdings may be necessary in case of disappearance of the holding or important changes to the unit that could affect, to a significant extent, its agricultural outputs.

Disappearance of a holding

- An agricultural household moving from where it was initially surveyed to another place (e.g., for migration, or another reason).
- An agricultural enterprise changing the location of its headquarters.
- An agricultural holding (household/non-household) completely merging with another holding. In the household sector, for instance, two individual households may merge into a single one through marriage.

Specific change to the holding

- An agricultural holding splitting into two or more different holdings. Household members may leave the household with agricultural parcel or other important assets and constitute independent households.
- An agricultural holding splitting into many entities, some entities being independent holdings and other entities merging with other holdings. For example, a member of an agricultural household may join another household through marriage.
- Similarly, an agricultural holding may welcome parts of another holding joining with agricultural assets such as land, livestock, etc.

b) How far to track?

To avoid biases in cross-sectional estimation, it is preferable to limit the geographical area of the tracking to the geographical domain in which the holding was sampled. For instance, in the framework of a two-stage design, the tracking areas would be the primary sampling units (PSUs). If the unit was sampled in an enumeration area considered a PSU, tracking will not be performed if the unit moved out of the PSU. This approach could affect the quality of estimates of change or other thematic analyses, but cross-sectional estimates are a priority for the survey programs.

XII. Integration in existing statistical systems

Countries seeking to join the 50x2030 Initiative may already have an agricultural and/or household surveys that are conducted regularly, as part of the national statistical system. Depending on each country's situation, some recommendations are provided below.

XII.A. Both agricultural and household surveys exist in the country

If the country wants to keep separate surveys for agriculture and households, then they may use the data integration model with the two sources of microdata to develop integrated agricultural and household microdata for analyses. A separate document is being developed on microdata integration.

If the country is willing to integrate the two survey operations, then two options could be explored:

(i) the two samples may be merged (at least in rural areas) every three years for a single survey operation using the integrated questionnaire (which is to be adapted to the country context). This supposes that the household survey covers a representative sample of households in the country and that the agricultural survey covers both household and non-household sectors. This option may not be cost effective as the new dispersion of the final sample will increase operational costs compared to the integrated sampling design proposed here. The probability of selection of the units in the final sample may be difficult to calculate (especially if the sampling designs of the two samples are different), and alternative estimation options, such as using multi-frame estimators could be explored.

(ii) a new integrated agricultural and household sample may be selected following the sampling strategy proposed here. This is the preferred and most cost-effective option.

It is important to note that integrating the operations of the two surveys may result in institutional challenges if the surveys are implemented by different government departments.

XII.B. Only an agricultural survey system exists

In addition to the sample of agricultural households covered by the existing agricultural survey, a complementary sample of non-agricultural households may be selected for the years in which the ILS-HH survey is administered. The final sample of households may not be fully representative. In fact, the size of the existing sample of agricultural households may not be sufficient for reliable estimation of some household-related indicators, especially if the country is using an area frame for agricultural surveys.

Here again, the best option is to select a new integrated agricultural and household sample.

XII.C. Only a household survey exists

Depending on the number of agricultural households in the sample of households compared to the required number of agricultural households for reliable estimation of agricultural statistics, the existing sample may be used for data collection in the years in which the ILS-HH survey is administered, otherwise a new integrated sample should be designed. If the existing sample can be used, the subpopulation of agricultural households in the sample can also be used for annual agricultural surveys, supplemented by a sample of non-household sector holdings.

XIII. References

50x30 Initiative. (2020). A Guide to the 50x2030 Data Collection Approach: Questionnaire Design. Technical Paper Series #2. Rome.

Abreu, D.A., Lawson, L. A., and Hickman, S. (2018). *Assessment of a Review Process for the 2017 Census of Agriculture.* Proceedings of the Joint Statistical Meetings Survey Research Methods Section.

Arcos, A., Molina, D., Rueda, M., & Ranalli, M. G. (2015). *Frames2: A Package for Estimation in Dual Frame Surveys.* The R Journal, 7-1, 52-72.

Baffour, B., Haynes, M., Western, M., Pennay, D., Misson, S., Martinez, A. (2016). *Weighting strategies for combining data from dual-frame telephone surveys:* Emerging evidence from Australia. Journal of Official Statistics, 32, 549-578.

Bankier, M. D. (1986). *Estimators based on several stratified samples with applications to multiple frame surveys.* Journal of the American Statistical Association, 81(396):1074–1079.

Bankier, M.D. (1988). "Power allocations: determining sample sizes for subnational areas." *The American Statistician* 42, 174-177.

Barcaroli, G. Ballin, M. Odendaal, H. Pagliuca, D. Willighagen, E. Zardetto D. (2020*). SamplingStrata: optimal stratification of sampling frames for multipurpose sampling surveys*, R package. Version 1.5-1

Bethel, J. (1989). *Sample Allocation in Multivariate Surveys*, Survey Methodology, 15,47-57

Brick, J. M., Dipko, S. , Presser, S., Tucker, C. and Yuan, Y. (2006). Nonresponse bias in a dual frame sample of cell and landline numbers. Public Opinion Quarterly, 70(5), 780—793.

Brito, J. A. D. M., Veiga, T. M. da, & Silva, P. L. do N. (2019). *An optimisation algorithm applied to the one-dimensional stratification problem*. Survey Methodology, 45(2), 295–315.

Chauvet G., Tandeau de Marsac, G. (2014*). Estimation methods on multiple sampling frames in two-stage sampling designs.* Survey Methodology, Vol. 40, No. 2, p. 335-346.

Cochran, W.G. (1977). *Sampling Techniques*. 3rd Edition. John Wiley & Sons: New York, USA.

Falorsi, P.D. Bako, D. Righi, P. Piersante, A. (2015). *Integrated Survey Framework*. FAO Publication. Rome

FAO (2015a). *World Census of Agriculture 2020. Volume 1: Programme, concepts and definitions*. FAO Publication. Rome.

FAO (2015b). *Handbook on Master Sampling Frames for Agricultural Statistics*. FAO Publication. Rome.

FAO (2017). *Handbook on the Agricultural Integrated Survey (AGRIS)*. FAO Publication. Rome

FAO (2018a). *Guidelines on the measurement of harvest and post-harvest losses. Recommendations on the design of a harvest and post-harvest loss statistics system for food grains (cereals and pulses).* FAO Publication. Rome

FAO (2018b). *Accelerated Technical Assistance Plan for Africa. Global Office Final report*. Technical Report Series GO-44-2018. FAO Publication. Rome. Available at http://gsars.org/en/accelerated-technical-assistance-plan-for-africa-global-office-final-report/

FAO. (2018c). *Guidelines on improving and using administrative data in agricultural statistics*. FAO Publication. Rome. Italy.

Ferraz, C. 2018. Master Sampling Frame: The Field Experiments conducted in Brazil. GSARS Technical Report: Rome

Fuller, W. A. Burmeister, L. F. (1972). *Estimation for samples selected from two overlapping frames*. In ASA Proceedings of the Social Statistics Sections, pages 245–249.

Fuller, W.A. (2009). *Sampling Statistics*. Wiley

Hartley, H. O. (1962). *Multiple frame surveys*. In Proceedings of the American Statistical Association, Social Statistics Sections, pages 203–206.

Hartley, H. O. (1974). *Multiple frame methodology and selected applications*. Sankhya C, 36(3):99–118.

Kalton, G. Anderson, D. W. (1986). *Sampling rare populations*. Journal of the Royal Statistical Society A, 149 (1):65–82.

Kish, L. (1965). *Survey Sampling*. John Wiley & Sons: New York, USA.

Kish, L. (1987). *Statistical design for research*. New York, NY: John Wiley & Sons.

Kokan, A. R. (1963). *Optimum Allocation in Multivariate Surveys.* Journal of the Royal Statistical Society. Series A (General), 126(4), 557.

Kozak, M. (2006). *On Sample Allocation in Multivariate Surveys. Communications in Statistics* - Simulation and Computation, 35(4), 901–910.

Lavallée, P. (2007). *Indirect Sampling*. Springer: Ottawa

Lessler, J.T. Kalsbeek, W.D. (1992). *Nonsampling errors in surveys*. John Wiley & Sons Inc.: New York, US

Lohr, S.L., and Rao, J.N.K. (2006). *Estimation in multiple-frame surveys*. Journal of the American Statistical Association, 101, 1019-1030.

Lohr, S. L. (2009). *Sampling: design and analysis*. Nelson Education

Lohr, S.L. (2011). *Alternative survey sample designs: Sampling with multiple overlapping frames*. Survey Methodology, Vol.37 no.2, p. 197-213.

Mecatti, F. (2007). *A single frame multiplicity estimator for multiple frame surveys*. Survey Methodology, 33, 151-157.

Singh, A. and Wu, S. (1996). *Estimation for multiframe complex surveys by modified regression.* Proceedings of the Statistical Society of Canada, Survey Methods Section,n, pages 69–77.

Singh, A. and Wu, S. (2003). *An extension of generalized regression estimator to dual frame surveys*. Proceedings of the Joint Statistical Meeting - Section on Survey Research Methods, pages 3911–3918.

Singh, A. and Mecatti, F. (2011) *Generalized Multiplicity-Adjusted Horvitz-Thompson Type Estimation as a Unified Approach to Multiple Frame Surveys*. Journal of Official Statistics, 27, 633-650.

Sitter, R. R. (1997). *Variance Estimation for the Regression Estimator in Two-Phase Sampling*, Journal of the American Statistical Association, 92:438, 780-787

Skinner, C. J. (1991). *On the efficiency of raking ratio estimation for multiple frame surveys*. Journal of the American Statistical Association, 86(415):779–784.

Skinner, C. J. Rao J. N. K. (1996). *Estimation in dual frame surveys with complex designs.* Journal of the American Statistical Association, 91(443):349–356.

Tillé, Y. (2016). *Unequal probability inverse sampling*. Survey Methodology, 42(2), 283–295. https://doi.org/10.1002/9781118162934.ch6

U.N. (2017). *Principles and Recommendations for Population and Housing Censuses- Revision 3*. United Nations Publication. New York, US

Valliant, R., Dever, J. A., & Kreuter, F. (2015). Effects of cluster sizes on variance components in two-stage sampling. *Journal of Official Statistics*, *31*(4), 763-782.

Valliant, R., Dever, J. A., and Kreuter, F. (2018). *Practical tools for designing and weighting survey samples*. 2nd edition. New York: Springer.

Vasconcellos, M. T. L. de, Silva, P. L. do N., & Szwarcwald, C. L. (2005). *Sampling design for the World Health Survey in Brazil.* Cadernos de Saúde Pública, 21(S), S89–S99.

Witoelar, F. (2011). *Tracking in Longitudinal Household Surveys.* The World Bank. Washington, DC:

Young, L.J., Lamas, A.C., & Abreu, D. A. (2017). The 2012 Census of Agriculture: a capture–recapture analysis. *Journal of Agricultural, Biological and Environmental Statistics*, *22*(4), 523-539.

Young, L. J., Hyman, M., & Rater, B. R. (2018). Exploring a big data approach to building a list frame for urban agriculture: A pilot study in the city of Baltimore. *Journal of Official Statistics*, 34(2), 323-340.