



Food and Agriculture
Organization of the
United Nations



Sampling guidance for SDG Indicator 2.4.1

11/08/2021

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Acknowledgements

This document has been prepared in support of the methodological concept note of SDG Indicator 2.4.1, particularly the sampling design aspects of the indicator by Food and Agriculture Organization of the United Nations (FAO) in collaboration with Global Strategy to improve Agricultural and Rural Statistics (GSARS).

The author, Dramane Bako would like to thank all those who have contributed to the different aspects of the document especially; Arbab Asfandiyar Khan from Statistics division of FAO, Amy Heyman and JeanMarc Faures of Strategic Programme on Sustainable Agriculture of FAO for their continued supervision and suggestions regarding the content, structure and further improvements of the document.

Introduction

The methodological note on the SDG Indicator 2.4.1 (FAO, 2019) discusses the data sources for the indicator including classical statistical surveys. The assessment of most of the sub-indicators at the national level requires the availability of specific data collected at the agricultural holding level and that can be done through censuses or sampling surveys. Surveys would be preferred over Census as cost effective solution and essential for the required frequency (every 3 years).

The cost-effective recommendation is to collect data on SDG 2.4.1 through existing surveys in the country. If need be, an ad hoc survey can be implemented for the specific purpose of the indicator. This guidance note will explore and discuss options as well as the corresponding estimation perspectives regarding sampling issues for the measurement of SDG 2.4.1. The first part of this note will discuss the design of that ad hoc survey. The second part will provide guidance on the use of existing surveys covering both agricultural and non-agricultural surveys.

1 Sampling design of a specific survey for SDG 2.4.1

This section will discuss the main features of the design of a specific survey considering the data requirements of SDG 2.4.1.

1.1 Observational units and target population

The observational unit for the measurement of SDG 2.4.1 is the agricultural holding in both household and non-household sector as defined by the FAO's World Programme for the Census of Agriculture 2020 (FAO, 2015):

- **Agricultural holding:** economic unit 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.
- **Holdings in the household sector (“household farms”):** agricultural holdings operated by household members
- **Holdings in the non-household sector (“non-household farms”):** agricultural holdings such as corporations and government institutions. The definition of these holdings may differ from one country to another.

However, the agricultural activities to be considered are crop and livestock production. Forestry, aquaculture and fisheries are not in scope of indicator 2.4.1. The target population is therefore all agricultural holdings producing crops or livestock.

1.2 Sampling units and frame

The recommended sampling unit is the agricultural holding allowing relevant stratification based on the typology of the holdings. The sampling frame is accordingly the complete list of all agricultural holdings in the country. The frame can be developed through the census of agriculture. A cost-effective approach for census and recommended by FAO is to link it with the population census by incorporating screening questions in its questionnaires. For the purpose of SDG 2.4.1, the screening questions should include relevant stratification variables (see section on stratification below).

1.3 Reporting units

All information needed from the holdings can be collected through declaration. Therefore, the reporting unit is any representative of the holding that can provide the required information. For instance, with regards to household farms, the reporting unit can be the head of the household or other member of the household that has a good knowledge of the holding.

1.4 Estimation domains

The estimation domain is the country. However, if a country wants sub-national estimations of the SDG2.4.1, the estimation domain will be these sub national administrative areas (region, district, province etc.). That will necessitate larger sample size, thus higher survey costs.

1.5 Sampling design and estimators

For most countries, a two-stage sampling design may be suitable for the household-farms. Many developing countries are familiar with that design that has many operational and technical advantages. A simple random sampling is generally suitable for non-household farms. More information and recommendations regarding both single stage and two-stage sampling design including estimators and variance can be found in GSARS (2017, chapter 5). The indicator 2.4.1 being a ratio (therefore nonlinear), its variance may be calculated using approximations using e.g. a Taylor linearization.

1.6 Stratification

Stratification can contribute at a great extent to improve the precision of the estimations (Fuller, 2009). In general, the stratification variables used in classical agricultural surveys are related to the economic typologies of the holdings (size, activity etc.). Given the importance of environmental and social dimensions for SDG 2.4.1, corresponding stratification should be explored. In fact, for the specific purpose of SDG2.4.1, all variables related to the themes of the indicator would be a good candidate for an efficient stratification. For instance, a random sample composed of only farms locate in areas with poor soil thus low productivity will not allow a good assessment of themes No. 1, 2, 4 and 8. A suitable stratification will allow to not select such sample. Variables linked to many themes should therefore be preferred for stratification and be included in the census questionnaire. Particular stratification variables of interest for the indicator are type of activity (crops, livestock and mixed holdings) and irrigation (irrigated / non-irrigated holdings).

In case of a two-stage sampling design, a stratification of the primary sampling units (PSU) is advised. For the indicator 2.4.1, a stratification based on agro ecological zones in the country would be suitable at PSU level.

Table 1: Proposed themes for sustainability assessment

Dimension	Theme	Sub-indicators
Economic	1. Land productivity	Farm output value per hectare
	2. Profitability	Net farm income
	3. Resilience	Risk mitigation mechanisms
Environmental	4. Soil health	Prevalence of soil degradation
	5. Water use	Variation in water availability
	6. Fertilizer risk	Management of fertilizers
	7. Pesticide risk	Management of pesticides
	8. Biodiversity	Use of agro-biodiversity-supportive practices
Social	9. Decent employment	Wage rate in agriculture
	10. Food security	Food Insecurity Experience Scale (FIES)
	11. Land tenure	Secure tenure rights to land

Source: FAO: 2021.

Ideally, information required for stratification should be available in the sampling frame. Otherwise, two alternatives may be explored: (i) Two-phase sampling scheme and (ii) post-stratification to calibrate the sampling weights after data collection.

1.6.1 Two-phase sampling for stratification purpose

Given the potential benefits of the stratification for an indicator like SDG 2.4.1 it would be important to have good stratification variables in the frame for a proper stratification of the population before sampling. In case such variables are missing, an alternative is to use a double sampling scheme. That consists in selecting a first large sample to collect stratification variables and then perform a stratified subsampling through a single stage or two-stage sampling design.

For instance, let's suppose a country wants to stratify by the agricultural holdings the productivity of the land. Usually such information is not available in frames because quite difficult to collect in a census. To use a double sampling design, a first large sample of agricultural holdings can be first selected to collect data on planted crop area and production and livestock during the last agricultural season to compute the productivity of each holding. Then the large sample could be stratified by productivity level before selecting a subsample. This is feasible in a short time if farmers are able to provide reliable information on the area of their land and their agricultural production.

Estimators when using a double sample for stratification are discussed in Cochran (1977, page 327).

1.6.2 Post-stratification and raking

Post-stratification and raking are common methods used for weights calibration using information on the actual structure of the population after data collection. For instance, if the structure of the sample of agricultural holdings by type of activity (crops, livestock and mixed holdings) is different from the actual structure of the population (from any existing reliable source), these methods may be used to improve the precision of the estimations. Useful information (with application) on these techniques may be found in Valliant et al. (2013, pp 374-381).

1.7 Sample size

The methodology of the indicator requires reliable estimates of the proportions of each of the 11 sub-indicators n (SI_n) for the three levels of sustainability (l): desirable (d), acceptable (a) and unsustainable (u). This represents a total of 33 ratios to be estimated. However, for a given sub-indicator, accurate estimates of two out of the three levels is enough, the third ratio being equal to one minus the sum of the two others. In conclusion, a survey for the SDG 2.4.1 should consider a sample size adequate for estimating a least 22 ratios. Ideally, if previous information are available on all sub-indicators, minimum required sample sizes to achieve reliable estimate (based on expected precisions) could be calculated for each of the 33 ratios and the maximum of these sizes should be considered for the survey.

Following as much as possible notations of FAO (2019), for a given domain of estimation, let's consider:

- SI_{ln} : proportion of sub-indicator n that is classified as the level l ; $n = 1 \dots 11, l \in (d, a, u)$
- Y as agricultural area
- Z_{ln} as agricultural area with level of sustainability l for the of sub-indicator n
- p_{ln} : proportion of holdings with agricultural area sustainable as the level l for the sub-indicator n
- N total number of holdings

The indicator SI_{ln} is therefore:

$$SI_{ln} = \frac{Z_{ln}}{Y} \quad (1)$$

For a survey aiming to provide a precise estimation of SI_{ln} with a relative error ε and $(1 - \alpha)$ confidence interval, a minimum sample size m_{ln} is required. If $\widehat{V}(SI_{ln})$ and \widehat{CV}_{ln}^2 are respectively estimated variance and square of the Coefficient of Variation (CV) of an estimation of SI_{ln} , we have:

$$m_{ln} = \frac{z_{\alpha/2}^2 \widehat{CV}_{ln}^2}{\varepsilon^2} \quad (2)$$

From formula (1) and Särndal et al. (1992, p179), we have:

$$\widehat{V}(\widehat{SI}_{ln}) = \widehat{V}\left(\frac{\widehat{Z}_{ln}}{\widehat{Y}}\right) = \frac{1}{\widehat{Y}^2} \left[\widehat{V}(\widehat{Z}_{ln}) + \widehat{SI}_{ln}^2 \widehat{V}(\widehat{Y}) - 2\widehat{SI}_{ln} \widehat{cov}(\widehat{Z}_{ln}, \widehat{Y}) \right] \quad (3)$$

It can be noted that, for a given agricultural holding, $Z_{ln} = Y$ if the agricultural area of the holding is considered sustainable at the level l for the sub-indicator n ; otherwise $Z_{ln} = 0$.

Let's consider a variable X following a Bernoulli distribution with a probability of success p_{ln} . The variable Z_{ln} can be modelled as a product of two independent variables Y and X .

$$Z_{ln} = XY$$

The mean of Z_{ln} is then:

$$E(Z_{ln}) = E(XY) = E(X)E(Y) = p_{ln}E(Y)$$

The variance of Z_{ln} is:

$$\begin{aligned} V(Z_{ln}) &= V(XY) = E(X^2Y^2) - E(XY)^2 \\ &= E(X^2)E(Y^2) - E(X)^2E(Y)^2 \\ &= (V(X) + E(X)^2)(V(Y) + E(Y)^2) - E(X)^2E(Y)^2 \\ &= V(X)V(Y) + V(X)E(Y)^2 + V(Y)E(X)^2 \\ &= p_{ln}(1 - p_{ln})V(Y) + p_{ln}(1 - p_{ln})E(Y)^2 + p_{ln}^2V(Y) \\ &= p_{ln}V(Y) + p_{ln}(1 - p_{ln})E(Y)^2 \quad (4) \end{aligned}$$

The covariance mentioned in formula (3) is

$$\begin{aligned} cov(Z_{ln}, Y) &= E(Z_{ln}Y) - E(Z_{ln})E(Y) = E(XY^2) - E(XY)E(Y) \\ &= E(X)E(Y^2) - E(X)E(Y)E(Y) = E(X)(E(Y^2) - E(Y)^2) \end{aligned}$$

$$cov(Z_{ln}, Y) = p_{ln}V(Y) \quad (5)$$

From formulas (3), (4) and (5), it can be deduced that:

$$\begin{aligned} \hat{V}(\widehat{SI}_{ln}) &= \frac{1}{\hat{Y}^2} \left[\left(\widehat{SI}_{ln}^2 - 2\hat{p}_{ln}\widehat{SI}_{ln} + \hat{p}_{ln} \right) \hat{V}(\hat{Y}) + \hat{p}_{ln}(1 - \hat{p}_{ln})\hat{Y}^2 \right] \\ &= \left(\widehat{SI}_{ln}^2 - 2\hat{p}_{ln}\widehat{SI}_{ln} + \hat{p}_{ln} \right) \frac{\hat{V}(\hat{Y})}{\hat{Y}^2} + \hat{p}_{ln}(1 - \hat{p}_{ln}) \frac{\hat{Y}^2}{\hat{Y}^2} \\ \hat{V}(\widehat{SI}_{ln}) &= \left(\widehat{SI}_{ln}^2 - 2\hat{p}_{ln}\widehat{SI}_{ln} + \hat{p}_{ln} \right) \widehat{CV}^2(\hat{Y}) + \hat{p}_{ln}(1 - \hat{p}_{ln}) \frac{1}{N^2} \quad (6) \end{aligned}$$

For relatively large population (as the case of national surveys), $\frac{1}{N^2}$ would be very small and the second part of equation (6) can be neglected. Therefore, from equation (6) we have:

$$\widehat{CV}_{ln}^2 = \frac{V(\widehat{SI}_{ln})}{\widehat{SI}_{ln}^2} = \frac{1}{\widehat{SI}_{ln}^2} \left(\widehat{SI}_{ln}^2 - 2\hat{p}_{ln}\widehat{SI}_{ln} + \hat{p}_{ln} \right) \widehat{CV}^2(\hat{Y}) \quad (7)$$

In conclusion, minimum sample sizes m_{ln} required for estimating the indicators SI_{ln} can be calculated using existing information from a previous survey and equations (2) and (7) above. Information required from the survey are (i) estimated coefficient of variation of estimated total agricultural land, (ii) estimated proportion \hat{p}_{ln} and (iii) estimated ratios \widehat{SI}_{ln} . In case there is no previous survey, a pilot survey may be conducted.

The final sample size m for the survey will be then:

$$m = \max_{l,n} m_{ln}$$

For most estimation domains in countries, the sampling fractions are expected to be low. However, in case a specific estimation domain has a modest size, a finite population correction can be made if the sampling fraction is more than 5%. The corrected sample size m^* will be:

$$m^* = \frac{m}{1 + \frac{m-1}{N}} \quad (8)$$

It is suggested to enlarge the sample size to account for possible nonresponses. In addition, in case a Simple Random Sampling is not used, this sample size should be multiplied by an estimation of the design effect (\tilde{D}_{eff}). Therefore if r is the expected response rate, the final sample size will be:

$$\tilde{m}_d = \frac{1}{r} \times \tilde{D}_{eff} \times m^* \quad (9)$$

In case of a two-stage sampling design, the corresponding size of the sample of PSU will simply be the sample size of the holdings divided by the number of interviews planned in each PSU (usually 10-15).

1.8 Sample allocation in strata

Given the number of indicators that should be estimated from the survey for the assessment of SDG 2.4.1, a proportional allocation of the sample in strata would be adequate here to ensure the achievement of the estimation goals. A multivariate sample allocation could be also explored in such context.

1.9 Case of nonexistence of frame

In case there is no suitable and updated frame in the country to select a sample for a survey for SDG 2.4.1, a well-known alternative for household farms is to select a sample of PSU (enumeration areas, counties, villages...) and then make a complete listing of holdings in these PSU to select the final sample of holdings.

For non-household farms, administrative data (e.g. register of agricultural corporations) can be used to build a frame for sampling purposes.

2 Collecting SDG 2.4.1 data from an existing survey

In case, regular surveys are implemented in the country, a cost-effective option is to take advantage of them to collect data for SDG 2.4.1 estimation. This section will explore the main issues that may arise regarding the data requirements of SDG 2.4.1 and propose options for improvement including how to address the corresponding estimation issues.

2.1 Data coverage

In case an existing survey is used, an important aspect that will need to be assessed is the data coverage. It is important to check that the questionnaires cover all the information required for SDG 2.4.1. A specific module incorporating the missing information may be needed for the purpose of the indicator.

2.2 Case of agricultural surveys

Countries having a well-established national agricultural statistics system can use the existing agricultural surveys to collect data for SDG 2.4.1. However, some adjustments maybe needed to improve the existing methodology especially if an area frame is used.

2.3 Observational and sampling units' issues

It is important to ensure that the observational unit of the survey is effectively the agricultural holding as defined in section 1.1. That is particularly important when an area frame is used. In that case the sampling unit is generally a segment or a point. The observational unit is sometimes the plot located in the segment or around the plot in which the sampled point is located.

The recommendation is to ensure that data are collected on the entire holding to which the plot belongs. Therefore, it will be necessary to locate the holder and to make an interview on the holding for the purpose of indicator 2.4.1. Broadly speaking, in any case, information should be collected at the agricultural holding level with a reporting unit that is able to provide them.

Estimation issues may arise when the sampling units are different from the required observational units that are agricultural holdings. One situation already described above is the case of a sample selected from an area frame. Apart from that, in some countries the sampling units in agricultural surveys are households especially when the final sample is directly drawn from the population census data. However, it may happen that a holding belongs to many households or a single household may possess many holdings. In such cases, the calculation of the weights of the holdings should take into account the multiplicities related eventually to the complexity of their links with the sampling units. GSARS (2015a and 2017) propose and discuss the use of the generalized weight share method of Lavallée (2007) in such situations. An illustration of this method is provided in section 2.3.2 below.

2.3.1 Sample size

If the sample size of the agricultural survey has been calculated for precise estimation of the agricultural area in the estimation domain (as usually done in many developing countries), this size could be higher or lower than the sample size required for estimating the indicator 2.4.1. If the size is higher than the one required for SDG 2.4.1, a subsample could be selected for the indicator. Otherwise all the sample should be considered for the indicator or the sample size should be increased especially if the gap with the required sample size is important.

In fact, for a given sub-indicator SI_{ln} , a subsample could be performed if $\widehat{CV}_{ln}^2 \leq \widehat{CV}^2(\hat{Y})$. From the formula (8), this is equivalent to:

$$\frac{1}{\widehat{SI}_{ln}^2} \left(\widehat{SI}_{ln}^2 - 2\widehat{p}_{ln}\widehat{SI}_{ln} + \widehat{p}_{ln} \right) \leq 1 \Leftrightarrow \widehat{SI}_{ln}^2 - 2\widehat{p}_{ln}\widehat{SI}_{ln} + \widehat{p}_{ln} \leq \widehat{SI}_{ln}^2 \Leftrightarrow \widehat{SI}_{ln} \geq \frac{1}{2} \quad (10)$$

Equation (10) provides then a condition necessary for using subsampling for a sub-indicator n classified as the sustainability level l . In practice, this condition should be checked for all ratios SI_{ln} before opting for subsampling. Otherwise, the whole sample should be considered for the indicator 2.4.1.

Complementary sample

In case the sample being used for the existing survey is considered non-convenient for SDG 2.4.1. for some reasons including an inadequate coverage of a specific type of holdings or the holdings of a specific area, a complementary sample can be selected to improve the coverage in case the existing sample cannot be completely renewed.

2.4 Case of non-agricultural surveys

In some developing countries, there is no specific agricultural surveys but some households' surveys are conducted and sometimes a few agricultural data are collected. In general, such surveys are not designed for agricultural statistics; consequently, they could not produce reliable estimates of the basic agricultural data like the crop planted area or production. In some case, the agricultural sector is considered in the design of these surveys but the households are still sampling and observational units. One example of these late cases is the Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA) of the World Bank.

Therefore, these surveys are not advisable for an indicator like SDG 2.4.1. However, if conducting a specific survey is not possible two alternative approaches may be adopted: selection of a complementary sample and indirect sampling of agricultural holdings.

2.4.1 Use of a complementary sample

Here again, a complementary sample can be selected to be surveyed in addition to the sample of the non-agricultural survey. A first step would consist in assessing the proportion of units of the existing sample that practice agriculture. That will provide an idea on the coverage of the units of interest in each estimation domain. For the domains in which the coverage is poor, the selection of a complementary sample can be explored to collect data.

In case the non-agricultural survey is a household survey, the selection of a complementary sample of the non-household farms is compulsory.

2.4.2 Indirect sampling

The second option is to use an indirect sampling framework to estimate the weights of the units of interest (agricultural holding). That is possible if each holding in the country is linked in a way to at least one sampling unit of the non-agricultural survey. The plan is to collect SDG 2.4.1 data on all holdings linked to the sampled units of the survey. The weight of the holdings can be estimated using the generalized weight share method (GWSM) of Lavallée (2007).

To illustrate, suppose the sampling unit of the non-agricultural survey is the household. The link between a household and a holding can be defined as follow: “*a household is linked to a holding if the household owns all or part of this holding*”. Let us consider L_{if} as the indicator of the link between the holding f and the household i . The variable L_{if} is equal to 1 if there is a link, and 0 if there is no link. Therefore $L_f = \sum_i L_{if}$ is the total number of links of the holding f with the population of households.

Let us assume that a given holding f is linked to s^f households in the sample of the non-agricultural survey ($s^f \neq 0$) and linked to t^f other households that have not been selected in that sample. If w_i is the sampling weight of the household i , the weight w_f of the holding f using the GWSM is

$$w_f = \frac{\sum_i L_{if} w_i}{\sum_i L_{if}} = \frac{\sum_i L_{if} w_i}{L_f} = \frac{\sum_{i=1}^{s^f} w_i}{s^f + t^f} \quad (11)$$

Conclusion

To conclude, this work provides guidance to countries on sampling and estimation for the production of statistics on the SDG 2.4.1 which is the proportion of agricultural area under productive and sustainable agriculture. The indicator can be estimated either by using an existing survey or by implementing a specific survey. However, the cost-effective recommendation is to use existing agricultural surveys or households' surveys collecting agricultural data. The document discusses the sampling and estimation issues for all options and provide recommendations for reliable estimation of the indicator.

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