Food and Agriculture Organization
of the United Nations

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)

Publication prepared in the framework of the Global Strategy to improve Agricultural and Rural Statistics

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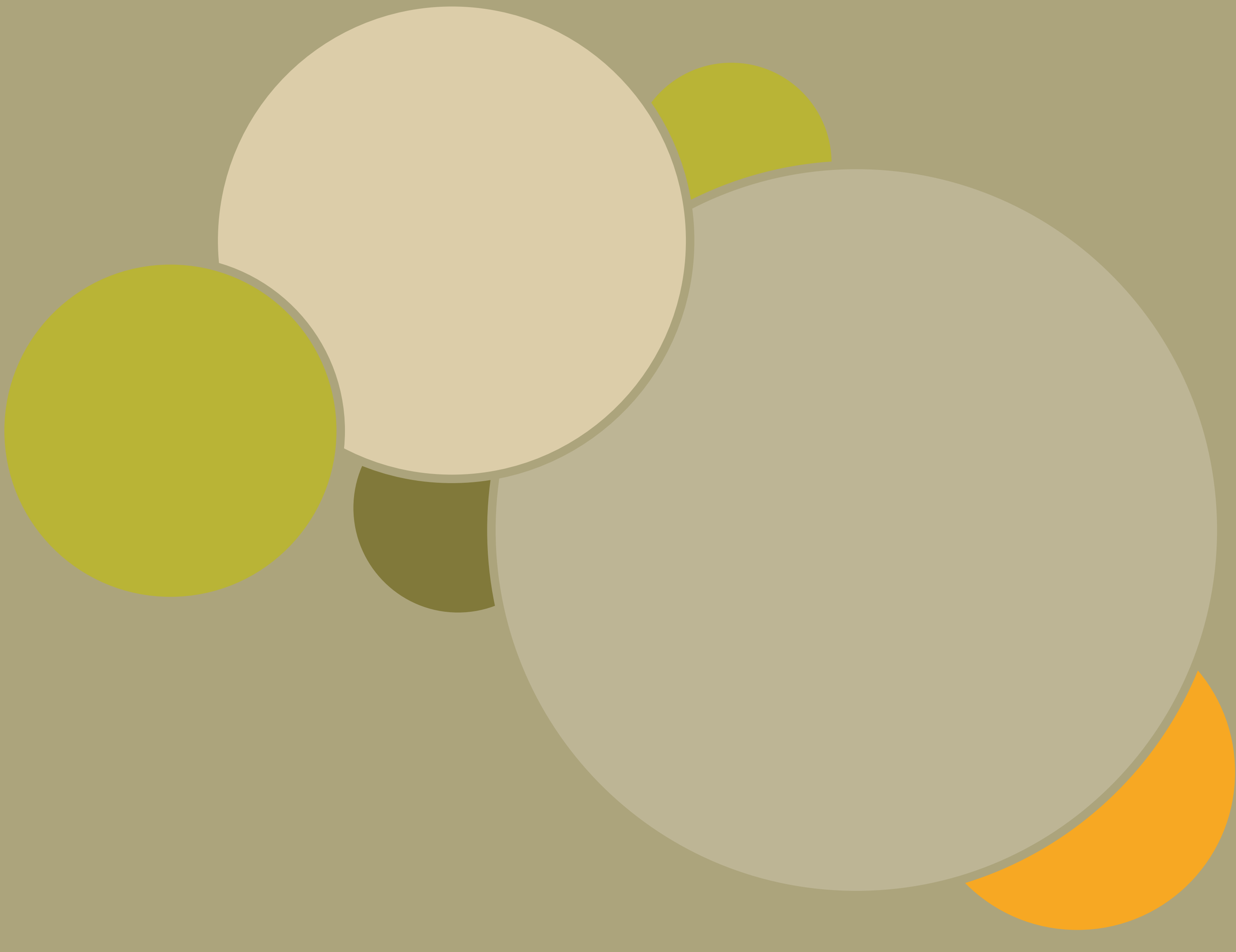
April 2018



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Acronyms

ANOVA	Analysis of variance
APHLIS	African Post-Harvest Loss Information System
FAO	Food and Agriculture Organization of the United Nations
g	gram
GRBD	Generalized Randomized Block Design
GSARS	Global Strategy to improve Agricultural and Rural Statistics
ha	hectare
HPHL	Harvest and Post-Harvest Loss
IRRI	International Rice Research Institute
kg	kilogram
LSD	least significant difference
OLS	Ordinary Least Squares
PHFLA	Post-Harvest Food Loss Assessment
PHL	Post-Harvest Loss
PSU	Primary Sampling Unit
RCBD	Randomized Complete Block Design
SDG	Sustainable Development Goal
SSU	Secondary Sampling Unit
TGM	Thousand Grain Mass method
TSU	Tertiary (or Final) Sampling Unit
UNDP	United Nations Development Program
UNID	United Nations Industrial Development Organization
VC	Value Chain
WLS	Weighted Least Squares

Acknowledgments

These Guidelines are the result of a research project undertaken within the Global Strategy to improve Agricultural and Rural Statistics (GSARS), a statistical capacity-building initiative whose Global Office is hosted by the Statistics Division of FAO. The Guidelines build upon methodologies presented in other papers, technical reports and manuals published by FAO and other organizations. They provide recent findings on the measurement of harvest and post-harvest losses in developing countries.

This document is the result of a collective endeavour of several statisticians working for GSARS and other teams of the FAO Statistics Division. Most of the research within this project since 2014, as well as the drafting of the Guidelines, was undertaken by Mbaye Kebe, international consultant for FAO. Carola Fabi (2014–2016) and Franck Cachia (2016–2017) have acted as focal points for this project, both coordinating and participating in the technical developments, under the overall supervision of Naman Keita (2014–2015) and Flavio Bolliger (2015–2017).

Special thanks are extended to the experts who have peer-reviewed the Guidelines, especially the IASRI team led by Tauqueer Ahmad. The many constructive comments and inputs received from the group have greatly contributed to improve the quality of the final document.

These Guidelines have been edited by Sarah Pasetto.

As some of the approaches recommended in these Guidelines are tested and implemented in an increasing number of countries, the need will arise to update, enhance or revise the methodologies and measurement frameworks. To this end, we invite the users of these Guidelines to communicate any suggestions they may have to GSARS, for incorporation in future versions of this document.

1

Introduction

The improvement of methods for estimating post-harvest losses (PHL) was identified by the member countries of the Food and Agriculture Organization of the United Nations (FAO) as a priority research topic to be included in the research activities of the Global Strategy to improve Agricultural and Rural Statistics (hereafter, GSARS or Global Strategy). In particular, the objective of the research on this topic is to develop cost-effective statistical methods for measuring PHL[1], focused but not limited to their use in developing countries.

The research activities commenced with a broad literature review that included previous FAO publications on the measurement of PHL, as well as academic papers, publications from other public institutions – especially international organizations – and relevant country experiences. In the context of the GSARS research activity on PHL, several technical reports have been produced that present the conceptual framework of, and provide a synthesis of suitable methods and techniques for, assessing PHL; identify key issues; and craft the basic foundational elements for developing improved methodologies to measure PHL. The material was reviewed by a small group of FAO experts and was presented at a technical workshop held in Washington, D.C. in February 2015, attended by national and international institutions active in this field of research. The final output of this first phase of research was published in the form of a Working Paper[2] in September 2015. The document is available on the Global Strategy's website.

During an Expert Group Meeting held in Rome in April 2015, the concepts and definitions relating to PHL were further clarified and discussions were held on gaps analyses, methodological options and related field-test designs that countries could adopt to fill those gaps. Following these discussions, a field test study of on-farm PHL was conducted in Ghana from October 2016 to March 2017. In parallel, a desktop study was done with data provided by Malawi for its 2009/2011 Post-Harvest Loss Surveys. The microdata was analysed and an attempt was made to identify the most important explanatory factors of PHL in that country. The outcome of the gaps analysis, methodological revisions and tests were published in a second Working Paper in April 2017[3].

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1 For the sake of conciseness, unless stated otherwise, in this publication the term "post-harvest losses" (PHL) describes what is rigorously defined as harvest losses (occurring **during** harvest) and post-harvest losses (occurring **after** harvest). Chapter 3 provides formal definitions. Indeed, even though these concepts are conceptually different, researchers and policy analysts often group them into the single term of "post-harvest losses".

2 GSARS. 2015. *Improving Methods for Estimating Post-harvest Losses - A Review of Methods for Estimating Grain Post-Harvest Losses*. GSARS Working Paper No. 2. GSARS Working Paper: Rome.

3 GSARS. 2017. *Gaps Analysis & Improved Methods for Assessing Post-harvest Losses*. Working Paper No. 17. GSARS Working Paper: Rome.

The Guidelines aim to present cost-effective methods for measuring food grain losses that could be used especially by developing countries to generate timely and quality data. This focus on cost-effective assessments is driven by the growing attention devoted to decreasing the cost of collecting data among national governments and international agencies.

Given the diversity of circumstances prevailing in different countries, the recommendations presented in this document should not be regarded as definitive or universally applicable; instead, they are intended to provide general guidance on various key issues that need to be considered by national practitioners, as well as examples of how they have been addressed in other countries.

2

Rationale, scope and purpose of the guidelines

2.1 RATIONALE

The 1996 World Food Summit defined food security as a situation that exists when: "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs, and food preferences for an active and healthy life."[1] Food security has three pillars: (i) food availability; (ii) food access; (iii) and food utilization. Food availability is determined by food produced in any given area, food brought into the area through market mechanisms, food held by traders and in government reserves, and food supplied by the government or aid agencies. All these determinants are directly affected by losses.

The issue of food losses is therefore of great importance in the efforts to combat hunger, raise incomes and improve food security in the world's poorest countries. Food losses have an impact on food security for poor people, on food quality and safety, on economic development and on the environment. Increasing the availability and quality of the data on food losses is necessary to implement, monitor and evaluate programs for loss reduction and prevention.

Better food loss statistics would also contribute to the accuracy of Supply-Utilization Accounts (SUAs) and Food Balance Sheets (FBSs), which are useful analytical frameworks for the monitoring of food security and nutrition in countries.

Historically, loss assessment studies have been associated with loss reduction or prevention programmes. The Seventh Session of the United Nations General Assembly, meeting in 1975, set the goal of reducing PHL by 50 percent by 1985. In 1976, FAO formulated a Special Action Programme that identified three major constraints on PHL prevention in developing countries:

- Lack of information about the amplitude of the losses, the nature of the losses, their causes and the most effective techniques for reducing or preventing them;
- Lack of infrastructure for implementing loss prevention measures;
- Lack of investment in food loss prevention.

1 FAO. 1996. *Rome Declaration on World Food Security and World Food Summit Plan of Action*. World Food Summit, 13–17 November 1996. Rome.

More recently, the importance of food losses has been reasserted by African heads of state with a commitment to "halve current levels of post-harvest losses by the year 2025".[2] Beyond the African context, reducing food losses and waste is among the top priorities of the Sustainable Development Goal (SDG) framework, which has assigned a specific target to food losses and waste: "[b] 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses".

Despite this increased attention, there are major data and methodological gaps regarding the measurement of global food loss and waste. When data are available, they are often accompanied by major uncertainties. Against this background, there is a clear need to develop, test and provide guidance on appropriate methodologies for the measurement of food losses[3].

The existence of major data gaps appears to contrast with the important amount of research conducted on the estimation of crop area, yield, production and losses in both developed and developing countries – all different, yet very closely related, disciplines. These Guidelines borrow heavily from the following key publications:

- Harris and Lindblad (1978). Some of the methods and techniques compiled by Harris and Lindblad were later reviewed and simplified by R.A. Boxall (1986), among others.
- FAO (1980). This manual was intended to serve as a guide to countries on the use of statistical methodology for assessing and collecting data on post-harvest food grain losses. The methods presented in this manual are based on the use of statistical surveys (using random sample designs) to collect the data, coupled with objective measurements and farmer declarations to estimate losses. These Guidelines will refer to this publication as FAO (1980).
- During the years between 1990 and 2000, researchers improved upon the existing methods, introducing rapid assessment methods and generalizing techniques such as visual scales and standard charts. J.A.F. Compton and J. Sherington (1998)[4], for instance, devised rapid assessment methods for stored maize cobs where weight losses were due to insect pests. From the year 2000 onward, additional methodological improvements were brought about by the African Post-Harvest Loss Information System (APHLIS) project and other researchers by combining rapid assessment methods, sampling-based field surveys and modelling to provide loss estimates.

A recent publication describing the methodology and results of a post-harvest survey conducted at national level in India for several crops is available in Jha *et al*. (2015). This publication is considered one of the most comprehensive descriptions of a structured survey-based approach to measure harvest losses and PHL combining farmer declarations with physical loss measurements. The present Guidelines borrow heavily from certain parts of this publication, especially regarding the sampling strategy recommended and the details of physical measurement.

2 African Union. 2014. *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. 23rd Ordinary Session of the AU Assembly 26–27 June 2014. Malabo.

3 Target 12.3, under SDG 12, which seeks to "ensure sustainable consumption and production patterns".

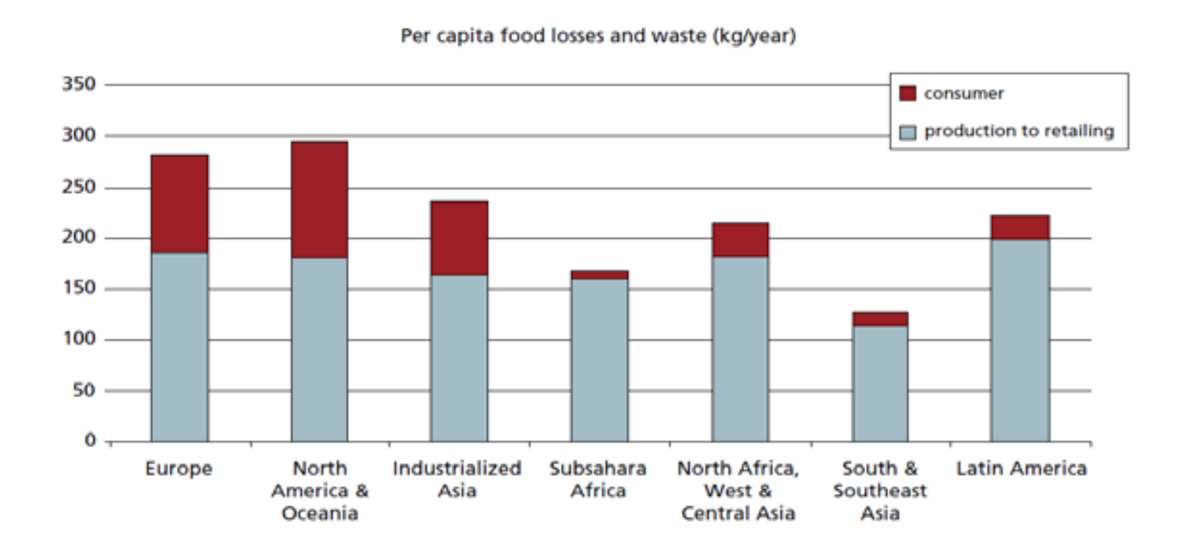
4 Compton, J.A.F. & Sherington, J. 1998. Rapid assessment methods for stored maize cobs: weight losses due to insect pests. Journal of Stored Products Research, 35(1): 77–87.

2.2 SCOPE

These Guidelines focus on those food losses that can take place at the production (harvest), post-harvest and processing stages in the food supply chain. Food losses occurring at the end of the food chain (retail and final consumption) are called "food waste" because they are, to a greater extent, the result of retailer and consumer behaviour (intentional losses) rather than of malfunctions in production or in the supply chain (unintended losses).

In medium- and high-income countries, food is to a significant extent wasted at the consumption stage, meaning that it is discarded even if it is still suitable for human consumption. In industrialized regions, significant losses also occur early in the food supply chains, albeit to a lower extent (see figure 1). In low-income countries, food is lost mostly during the early and middle stages of the food supply chain and much less food is wasted at the consumer level. This is why these Guidelines, addressed first and foremost to developing countries, focus on food loss – excluding, therefore, the retail and consumption stages. This distinction is clear from a theoretical or value chain perspective. In practice, however, a significant share of the consumption of most rural households in developing countries is satisfied by their own production. In this situation, on-farm losses will not be very different, or even separable from, losses at household or consumption level.

FIGURE 1. PER CAPITA FOOD LOSSES AND WASTE (KG/YEAR).



In principle, food PHL encompass grains (cereals and pulses), fruits, vegetables, fisheries, and livestock. For practical purposes, these Guidelines will focus mainly on the assessment of grain PHL; however, general indications on the assessment of losses for vegetables and fruits will also be provided.

2.3 PURPOSE AND TARGET AUDIENCE

The Guidelines propose an operational framework for generating cost-effective data and statistics on post-production grain losses within agricultural supply chains in developing countries. They provide basic information on and practical guidance for estimating grain losses by leveraging secondary data – complementing traditional loss estimation through sample surveys – and highlight conceptual, technical and human-related issues with statistical tools that may be used by countries wishing to improve their loss information system. Many countries have not undertaken full PHL surveys for various reasons, among which the unavailability of proper documentation and cost-effective methodologies for conducting the surveys. Properly conducted surveys tend to be complex and costly, involving the collection of samples of produce to be examined and analysed in laboratories. The methods and techniques recommended here are not infallible and may require further research and adjustment to fit individual country conditions. They will require the collaboration and cooperation of various specialists, such as statisticians, agronomists, biometricians and entomologists, working according to a multi-disciplinary approach.

These Guidelines are targeted at statisticians, administrators and decision-makers who are responsible for collecting data on food losses. They are intended to enhance the strengthening and harmonization of data collection.

3

Conceptual framework

3.1 INTRODUCTION

In these Guidelines, the term post-harvest food losses assessments (PHFLA) is used to describe the set of methods and tools to collect, process, analyse and disseminate data on food losses. The primary purpose of a PHFLA, as defined here, is to systematically and cost-effectively provide an objective picture of the food loss situation in a country at a specific time, so that timely and appropriate actions can be taken by decision-makers.

Before describing the components of such a PHFLA, it is important to clearly define and understand the main concepts that are used and manipulated in the field of food losses measurement. This is the objective of this chapter.

3.2 DEFINITION OF THE MAIN CONCEPTS RELATED TO FOOD LOSSES

Most of these definitions are taken from FAO (1980) and Boxall (1986) and are commonly accepted by the scientific community.

Food: Commodities that people normally eat. It includes the wholesome edible material that would normally be consumed by humans. Portions of the crop that are generally considered inedible, such as stalks, hulls and leaves, are not considered food. Crops mainly intended for animal feed are not considered food.

Grain: This term is used in these Guidelines in a broad sense and includes cereals and pulses. It also includes cereals on the head, ear or cob, as well as after threshing or shelling, and pulses both shelled and in pod.

Harvest: The deliberate act of separating the food material from the site of immediate growth or production, for instance the reaping of cereals, the picking of fruits, the lifting of fish from water, etc.

Post-harvest: The period beginning after separation from the site of immediate growth or production and ending when the food reaches its final use. For most PHL studies, as well as for these Guidelines, the end of the chain is reached when the grain or grain product is at a stage when it can be considered ready for final consumption.

Food loss: The measurable decrease in the quantity or quality of food produce. It is the result of any reduction in the availability of food or in the edibility, wholesomeness, or quality of food that reduces its value to humans. Food loss is considered as the unintended result of an agricultural process or technical limitation in storage, infrastructure, packaging or marketing (World Resource Institute - WRI, 2013). Food losses are often classified as direct or indirect.

Food waste: Term referring to food that is fit for human consumption but that is discarded either before or after it spoils. Hence, food waste is the result of negligence or a conscious decision to throw food away (WRI, 2013).

Direct (or quantitative) loss: The disappearance of food by spillage or consumption by rodents, birds, insects and other pests. It is measured as the loss in weight of commodities that would have been eaten if they had remained in the food chain. Losses can be the result of grain damage, which is characterized by superficial evidence of deterioration (for example, holed or broken grains). Weight losses are generally presented in two ways: (i) the actual weight of grain lost (an absolute loss, in kg or any other relevant physical unit); or (ii) as a percentage or proportion of a reference quantity, such as harvested quantities (relative loss). Finally, losses should be expressed for a given moisture content, which may vary depending on the crops. Indeed, weight reduction due to a decrease in moisture content, for example during drying, should not be accounted for as weight loss. These Guidelines focus on direct losses.

Indirect (or qualitative or nutritional) losses: The loss caused by a lowering of quality leading to its rejection as food, of its nutritional value or of its economic value, these three aspects being interrelated. The quality of a food commodity can be assessed against criteria such as appearance, shape, size, and sometimes, smell and flavour. The assessment of nutritional losses (a type of qualitative loss) generally requires in-depth laboratory analysis. Nutrient losses may be due to selective feeding by pests, which targets the most nutritious parts of grains. Qualitative losses, although relevant, will not be treated in these Guidelines.

Economic losses: The monetary equivalent of direct or qualitative losses. For direct losses, the economic loss can be estimated by multiplying the lost quantities by the market price for the commodity. For qualitative losses, such as a stock of grain that contains a higher proportion of broken kernels, the loss corresponds to the difference between the market price of first-quality grain (or the quality level that can usually be expected by the farmer) and the price corresponding to the actual quality level, multiplied by the quantities produced.

Pre-harvest losses: Losses that occur before the beginning of the harvesting process and that may be due to attacks by insects, mites, rodents, birds, weeds, or diseases afflicting and damaging crops.

Harvest losses: These occur during the harvesting process and may be due to shattering, mechanical damage and shedding of the grain from the ears to the ground.

Post-harvest losses (PHL): Any losses occurring after the separation of the product from the site of immediate growth (harvest) to the moment it reaches the consumer.

Post-production losses: The combination of harvest losses and PHL.

3.3 AN OPERATIONAL DEFINITION OF LOSS

There is a great degree of variation in the concepts and definitions of loss adopted by various institutions and researchers. To some extent, this can be explained by the fact that several post-harvest operations are paired with food grains, horticultural crops and livestock products. Multiple channels are also involved in the commodity flows from the producers to the consumers, thus painting a varied and complex scenario. Hence, for the development of a suitable methodology for PHL assessment, it is opportune to simplify the problem to the extent possible and to aim for practical feasibility in data collection and analysis.

For practical purposes, and for most institutions and researchers, **loss may be defined as a reduction in the weight of edible produce available for consumption**. This definition has been proven adequate and convenient mostly because of its simplicity. However, it does not explicitly address the reduction in weight due to the drying process. Drying may lead to a great reduction in weight; however, there is no loss of food value and therefore, such reduction should not be accounted for as loss. Therefore, quantitative losses should be measured at a given moisture content (at which the grain or commodity can be considered dry), such that losses due to factors such as the incidence of pests (insects, mites, fungi or bacteria, rodents and birds) and chemical or physical transformations (whether or not induced by environmental or climatic factors), can be properly measured. For transportation, stock movement and other losses caused by spilling, losses are normally estimated as the difference in weight between the quantity loaded and the quantity unloaded. For long transport operations, grain samples can be taken at the loading stage and at the unloading stage, and then examined for changes in moisture content and qualitative damage during transit.

The recommended approach to the assessment will hence be limited to the estimation of quantitative losses, consisting in the material rendered "unfit for consumption". Losses in quality, food value, taste, goodwill or reputation, seed vigour, etc., are very challenging to quantify and therefore will not be considered here. However, in cases where qualitative deterioration takes place to such an extent that the food material is rendered unfit for consumption and is rejected, this would amount to a quantitative loss.

Significant effects on the level of losses have been associated with farmers' practices during harvesting and in-field drying or stacking. Harvesting losses also generally increase with the slightest delay if the harvest is done beyond the time considered best by the farmer. Losses during in-field drying, transport, cleaning or winnowing, and platform drying have been observed to be relatively low; threshing or shelling losses are very much dependent on the methods used and the timing of the harvesting.

For losses arising during storage – due to insects and moulds – at farm level, the weight loss must always be related to the quantity in store at the time of the assessment.

3.4 THE AGRICULTURAL VALUE CHAIN

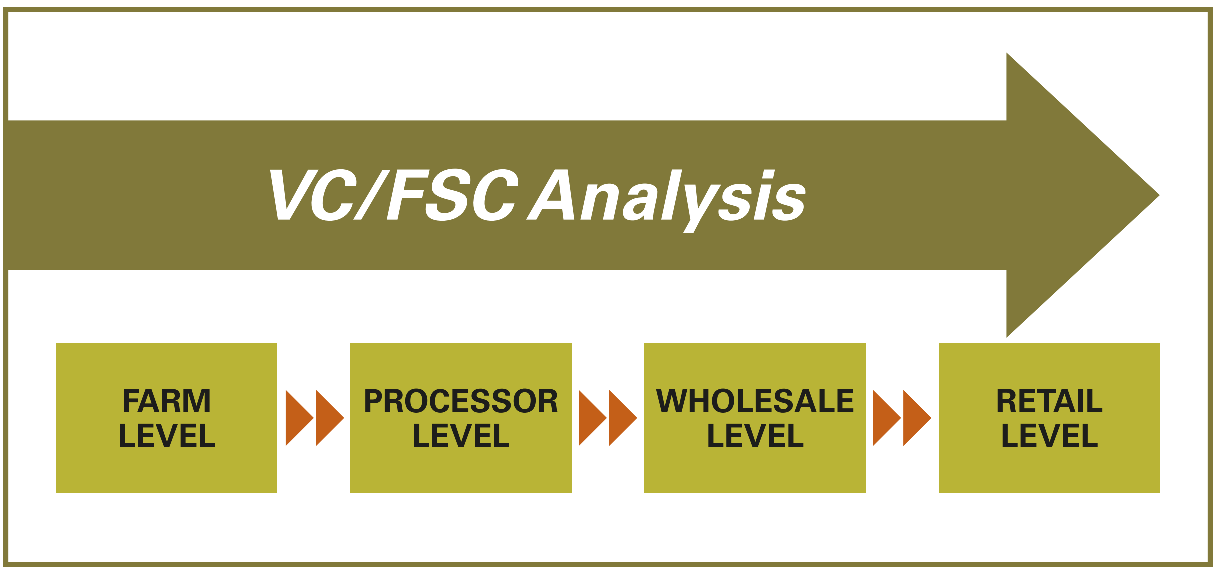
An efficient PHFLA should be based on identification of the segments of the supply chain where the losses are the most significant. A characterization and analysis of the chain for the selected commodities should therefore be undertaken prior to the start of the measurement activities. The main characteristics of supply or value chains are defined in this section. The procedures to conduct a value chain analysis are described in section 4.2.

Value chain: Kaplinsky and Morris (2002) define the value chain as the full range of activities required to bring a product or service from conception through the different phases of production, delivery to final customers and final disposal after use. These activities involve a combination of physical transformation of the commodity and the use of physical inputs, as well as services, from several suppliers at different points of the chain. The term "value chain" stems from the fact that at each stage of the supply chain, value is added to the product or service as it is processed. The value chain analysis is hence grounded on a specific market system, with structural and dynamic factors (price changes, supply shortages, etc.) affecting the contributions of each actor to the chain. The participants can be located domestically, spatially dispersed or not, or outside national borders. Some participants or suppliers may be specialized in carrying out a specific activity or, on the contrary, may be involved at several points of the chain as well as in many different supply chains.

Agricultural value chain: By extension, an agricultural value chain comprises of the activities of input supply, production, post-harvest management, storage, processing, marketing and distribution, or any other activity involved in the "farm-to-fork" continuum for a given product. A loose definition of an agricultural value chain would also include the external enabling environment, comprising private or public organizations involved in supporting each actor through the provision of a wide range of activities, from counselling (extension services, unions and corporations, local governments, etc.) to transport, communication, financial or any other business-related services.

Food supply chain (FSC): A specific type of agricultural supply chain comprising only of commodities intended to be produced and sold for human consumption, excluding non-food agricultural products such as fibre crops, tobacco and oil crops grown to produce fuel. The main actors of an FSC include input suppliers, farmers, middlemen (including agents, assemblers or collectors, and transporters), processors, wholesalers (including importers and exporters), retailers and final consumers. Figure 2 provides a simplified representation of a supply or value chain.

FIGURE 2. SIMPLIFIED VALUE CHAIN (VC) AND FSC.



Carrying out a supply chain analysis for a country's PHFLA enables identification of the actors within the supply chain that suffer the highest losses, which in turns allows for prioritizing the development and implementation of appropriate measurement methods and monitoring systems.

3.5 CAUSES OF GRAIN LOSSES

A complex interplay of various factors contributes to the losses that occur in the post-production system. These elements can be classified as follows:

- Biological and microbiological
- Biochemical and chemical
- Environmental and climatic
- Mechanical and technical
- Socio-economic.

As these factors impact one another, they ought not be treated or analysed separately. For example, climatic conditions (rain, temperature, humidity level, etc.) affect the physiological conditions of plants in the field or of the grain stored, as well as the degree of infestation by fungi, moulds and other pests.

Biological and microbiological factors: These comprise all losses due to pests of any sort which are capable of attacking undamaged grain (primary pests) as well as damaged grain (secondary pests). Insects, mites, rodents and birds fall in this category. Losses can be of both qualitative and quantitative nature, as food is consumed, damaged or contaminated by pests, especially during the storage period.
Several species of fungi (moulds, yeasts) also attack grains, some of them producing mycotoxins that can be detrimental to humans and animals (such as aflatoxin in groundnuts and maize).

Biochemical and chemical factors: Some of the chemical elements naturally present in stored commodities provide the bases for loss of nutritional value, flavour, texture and colour, for example through enzyme-activated reactions.

Environmental and climate factors: High humidity levels and temperatures can trigger an alteration of certain biochemical processes – such as oxidation and fermentation – that can lead to a deterioration of the grain in storage. These processes can also be altered by the concentration of certain substances contained in the air surrounding the grain, such as oxygen, carbon dioxide or nitrogen.

Mechanical factors: The different farm operations that are carried out manually or mechanically (harvesting, drying, shelling, threshing, cleaning, bagging, transportation, etc.) can cause damage to the grain, which then becomes more vulnerable to enzyme-mediated chemical changes and to attack by insects and other pests.

Socio-economic factors: These include the nature of the equipment and facilities used at the different points of the chain, the way the different operations are carried out by the actors (production practices), as well as the conditions in which production takes place. Regarding material and equipment, inadequate (or absent) storage infrastructure or the use of low-efficiency technology (such as threshing equipment leading to a high percentage of damaged grain) are examples of equipment-driven losses. Inadequate harvesting, packaging and handling skills are production practices that have a bearing on losses.

Regarding production conditions, the legal environment – through its imposition of quality standards that can affect the retention or rejection of food for human consumption – is another socio-economic factor that may explain losses. In addition, the economic environment is important: low commodity prices may push farmers to divert their production from food to feed markets or simply to increase storage time to wait for better market conditions, thereby increasing the risk of pest infestation and related damages and losses.

3.6 POST-PRODUCTION OPERATIONS AND CAUSES OF LOSSES

The main stages within the agricultural supply chain during which losses occur depend on the nature of the commodity under study and of the prevailing practices in the country or region of interest. In the case of grains (cereals and pulses), the following broad operations, and the associated causes of losses, may be distinguished.

Harvesting: The manual harvesting process includes cutting the crop, gathering, bundling and stacking. The same operations may be done mechanically by a harvester. At this stage, losses occur mainly due to the shedding of grains, with the amount of loss depending on the time of harvesting: if the harvesting operation is done late, then shedding is generally higher. When harvesting is done mechanically, a higher proportion of the grain may be damaged, resulting in additional losses.

Threshing or shelling: Grains are separated from the husk and plant to which they are attached. The process may be performed manually or mechanically using threshers, shellers or combine harvesters. When done mechanically, additional losses may occur due to grain damage during processing. However, this does not necessarily imply that losses are always lower when threshing or shelling is done manually, as mechanical threshers may reduce losses due to spillage.

Cleaning or winnowing: The process consists of cleaning the grain by blowing the chaff away from it. In doing so, losses occur because a certain amount of the edible grain passes into chaff. The cleaning operation may be done manually or mechanically (the winnower may be hand- or machine-operated). Contrary to the case of manual processes, the use of combine harvesters allows harvesting, threshing and winnowing to be performed in one single operation: in this situation, losses cannot be attributed to each activity.

Drying: Drying is often necessary to bring the moisture content of the grain to the recommended level for storage, selling or consumption. The causes of losses at the drying stage are similar to those arising during storage: damages and losses caused by pest infestation, rodents, birds, etc., especially if the grain is dried in the open air (yard, road, etc.), a common practice in developing countries for crops such as paddy, pearl millet or sorghum. Insufficient drying may also lead to fungal damage to grain during storage.

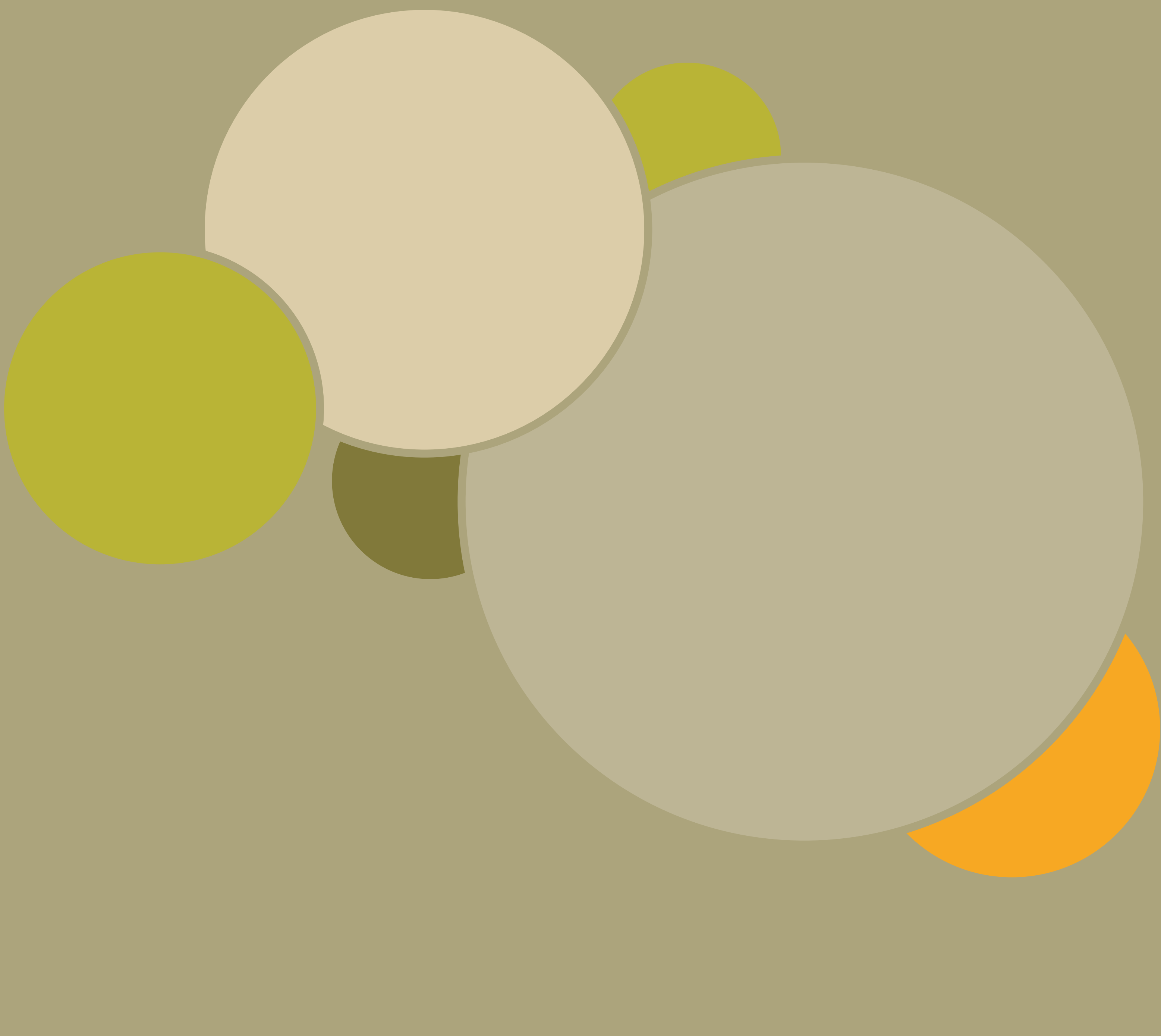
Storage: Grain can be stored by different actors, from the farmer to the wholesaler, using a variety of facilities and equipment, ranging from traditional granaries to metallic silos and sophisticated storage facilities with controlled temperature and humidity levels. The deterioration of stored produce, leading to weight or quality reduction, is principally caused by pest infestation, rodents, birds, etc., as well as by attacks by microorganisms (fungi, bacteria, and yeasts) and metabolic activity. Storage losses generally increase with storage time.

Processing: Food grains are subjected to different types of processing before reaching the market and being finally consumed. For instance, paddy rice is generally de-husked or dehulled to obtain brown rice, manually by hand pounding or, more commonly, by machines such as rice hullers. When processing paddy, additional operations such as pre-cleaning, de-stoning, parboiling (pre-milling treatment), polishing and glazing may also be required. During these operations, losses are essentially due to damage to the grain, certain grain kernels resulting broken, and to spillage. A key efficiency parameter for rice milling is the recovery in terms of whole grain and the percentage of broken grains resulting from the milling process. For example, according to the International Rice Research Institute (IRRI), a good rice mill will produce 50 to 60 percent of head rice (whole kernels), 5 to 10 percent of large broken kernels and 10 to 15 percent of small broken kernels[1]. Losses can be defined in relation to these efficiency standards.

Packaging, handling and distribution: Improper packaging of produce may facilitate pest infestation or the appearance of moulds and fungi leading to grain damage, weight loss, or rejection because of spoilage, especially if the produce is stored or transported for long periods. Improper handling may lead to grain damage and spillage, resulting in weight as well as quality losses. These losses may arise at different phases, for example during transport from farm to storage and from storage to market, at different points of marketing channels, and at the wholesale and retail levels.

Transport: During post-harvest operations, transport is involved on several occasions: harvested crop may need to be moved from the field to the threshing floor, and from there to the farm storage area, and finally from the storage area to the processing facilities and collecting markets. From those markets, crops may be transported by retailers to their shops or transported by wholesalers over long distances to distant or foreign markets by train, trucks, ships, etc. During these operations, which require multiple loading and unloading, spillage or pilferage entrain losses. In addition, transit losses may also occur because of damage to grain in trains, trucks, or ships caused by time-bound deterioration. In long-distance transport, grain may also be attacked by insects, fungi and other pests, similarly to what usually happens during normal storage.

1 http://www.knowledgebank.irri.org/ericeproduction/PDF_&_Docs/Teaching_Manual_Rice_Milling.pdf.



4

Principles for data collection and measurement

4.1 INTRODUCTION

Obtaining reliable information about losses for a wide range of commodities, chain processes and actors is challenging. Several approaches to meeting these challenges have been tested by researchers and practitioners in various countries, considering local circumstances and resource requirements. An ideal set of methods applicable in all situations does not exist, given the variability of contexts, objectives and resources involved.

Irrespective of the technique used, it is necessary first to have a sound understanding of the proper agricultural value chains that are of relevance to the country. Indeed, this information provides convenient guidance in choosing the appropriate time and place of assessment operations. In practical terms, this is done by identifying the most critical loss points in a country's post-harvest food system and concentrate the loss measurement, prevention and reduction efforts on those points. Methodologies for assessing PHL aim at providing outcomes that enable the determination of priorities for loss prevention and reduction efforts. Information on agronomic practices and on the natural environment are also important, as they can be utilized for stratification purposes and other improvements in the sample design.

This chapter presents the main PHL assessment methods for the general guidance of researchers, planners, survey designers and policy advisers, considering the different options available in function of the specific needs and requirements of these users.

It is essential that PHL assessment activities be as coordinated as possible with other primary data sources, such as standard agricultural or rural surveys. Most loss assessment studies have been conducted on a one-off basis and in complete isolation from one another and other potentially useful surveys. By coordinating data sources, annual agricultural production surveys with crop-cutting components, farm management surveys, food consumption and nutrition surveys, income and expenditure surveys, could all collect valuable and useful information for food loss assessments by "piggybacking" specific modules. Uniform concepts, definitions and measurement techniques should be used to the extent possible, to facilitate the integration of these data sources and their combined use. Countries are also encouraged to report and publish statistical quality indicators, including, for instance, standard sampling errors[1], following their loss assessment studies.

Finally, it should be borne in mind that the outcomes of surveys and loss assessments exercises are only valid for the conditions under which they were undertaken. Seasonal effects can affect the estimated loss levels significantly and should therefore be measured separately. This can only be done if the results of these studies are available for several years.

4.2 THE AGRICULTURAL VALUE CHAIN ANALYSIS: IDENTIFYING LOSS "HOTSPOTS"

4.2.1 Introduction and definitions

A proper agricultural value chain analysis should be conducted prior to the main assessment, to fully characterize and decompose the chain (actors, cost structures, spatial, seasonal dimensions, etc.) and identify the processes where most losses are likely to occur. This step is a crucial building block for the remainder of the exercise. The relevant actors to be covered by the assessment should be chosen according to the role they play along the supply chain: grain producers, processors, transporters, sellers, etc. In most instances, a substantial amount of pertinent data and information that the supply chain analysis could use will already be available. Sources of information include existing supply chain or industry analyses, broader country agricultural development or trade studies, investment climate studies, agricultural strategy documents, national and international databases, national poverty assessments and general country economic development studies.

Prior to undertaking a value chain analysis, the scope in terms of subsectors, products or commodities should be restricted to prioritize analysis in function of user needs. As the resources available for undertaking analyses are limited, a limited number of value chains to be analysed (among the numerous choices available) should be identified. For example, a country may be interested in focusing on the value chain of maize, using smallholders as the starting point. In doing so, value chains involving large producers (which may include transporters, processors and exporters) will be excluded. This choice may be motivated by the supposition, based on preliminary or incomplete evidence, that losses in the smallholder value chain are higher. The motivation may also derive from the existence of policy incentives (subsidies, loans, etc.) covering specific sectors (such as smallholders) and important food security crops (for example, maize), requiring better data for evaluation and monitoring purposes.

The World Bank (2007) provides detailed guidelines on the characterization and analysis of agricultural value chains, with a focus on sub-Saharan Africa. The United Nations Industrial Development Organization (UNIDO) has also established its approach to agro-value chain analysis and development, defining the value chain as describing "the

1 Non-sampling errors (which indicate the validity of the estimates of key indicators compiled from sample surveys) also constitute a useful measure of statistical quality. However, they are generally difficult to determine.

entire range of activities undertaken to bring a product from the initial input-supply stage, through various phases of processing, to its final market destination, and it includes its disposal after use. For instance, agro-food value chains encompass activities that take place at the farm or rural level, including input supply, and continue through handling, processing, storage, packaging and distribution. As products move successively through the various stages, transactions take place between multiple chain stakeholders, money changes hands, information is exchanged and value is progressively added. Macroeconomic conditions, policies, laws, standards, regulations and institutional support services (communications, research, innovation, finance, etc.) – which form the chain environment – are also important elements affecting the performance of value chains" (UNIDO, 2009).

4.2.2 Basic principles of value chain analysis

The most important principle to consider when conducting a value chain analysis is to map the actors participating in the production, distribution, marketing, and sales of a crop. The mapping characterizes the actors and quantifies the flows of crops along the chain, and possibly the destinations and volumes of domestic and foreign sales. Such details can be gathered from a combination of primary survey work, focus groups, participatory rural appraisals, informal interviews, and secondary agricultural data.

The entities to be surveyed (households, farms, intermediaries, mills, government institutions, etc.) and their role in the chain are identified through a mapping exercise, following the chain's selection. This mapping comprises two main elements: (i) a visual representation of the networks, to obtain a better understanding of the connections between actors and processes in a value chain; and (ii) a quantification of the interdependency between actors and processes in the value chain. A mapping exercise oriented towards the assessment of losses can be facilitated by answering the following questions:

- What are the different (core) processing steps in the value chain?
- Who are the actors involved in these processes and what do they do?
- What are the flows and stocks of commodities in the value chain?
- What is the volume of products and the number of actors?
- Where do the commodities originate from and where do they go?
- What types of relationships and linkages exist?
- What types of business services are feeding into the chain?
- What are the loss points in the chain by commodity, actor, and level or process?
- What are the estimated losses along the chain?

Based on the answers to these questions, it is possible to quantify the:

- Flows and stocks of commodities at different points of the chain;
- Volume and value of commodities handled, by actor;
- Geographical flow of commodities; and the
- Magnitude of quantitative and, possibly, economic losses at different points of the chain.

The outputs of a value chain analysis carried out in preparation to loss assessment typically include a set of maps, tables, descriptions of the chain process, diagrams of chain actors and their linkages, as well as flux diagrams of the chain processes with critical loss points. Examples are given in annex 1 to these Guidelines.

4.3 THE MAIN TYPES OF LOSS ASSESSMENT METHODS

4.3.1 Introduction

For each loss point targeted or identified through a value chain analysis, different types of assessment methods can be used. These methods are described in section 4.3.2 below. Guidance on how to select an appropriate method or a combination of methods is given in section 4.3.3. All loss assessment studies are based on two components: (i) the study design aspect; and (ii) the measurement approach.

The study design specifies which units should be surveyed and analysed, their number (for example, the size of a certain sample) and how to select them. Loss information is gathered for these units. They include well-circumscribed localities or geographical areas such as villages, farming households, traders, intermediaries and other chain actors, markets, fields, parcels, plots, storage structures like granaries, containers like bags, boxes, etc. The study design should clearly specify how to select these observational units: through random selection, on the basis of judgmental or purposive sampling, or other method. The study design also provides an indication on the number of units to be selected: few in the case of field trials or rapid assessments, for example, and numerous for household or farm surveys.

The measurement approach specifies how to measure losses and compute the related indicators, from the units defined and identified by the study design. The measurements can be either **subjective** (subjective measurements) or **objective** (objective or physical measurements). Subjective measurements are assessments or estimates provided directly by the respondent (farmer, technician of a processing facility, wholesaler, transporter, etc.), by the enumerator or by any other third party (expert, extension officer, etc.). Objective measurements consist in performing physical measurements using adequate instruments on the observational units: crop-cutting, sampling grain, measuring moisture content, etc. Visual scales, which allow for a quick identification of the loss percentage in function of different classes of grain condition, are considered in these Guidelines as an objective method, even though in many ways they occupy a middle ground between objective and subjective approaches. These measurements can be performed by the enumerator, the researchers or laboratory analysts, depending on the task. The different measurement techniques are described in section 4.4.

The type of a loss assessment method is characterized by how the data is collected (study design) and how losses are measured (measurement approach). Examples of loss assessment methods include rapid loss appraisals, field trials (or experimental designs), probability sample surveys based on declarations, objective measurements or a combination of both. Modelling (biophysical, statistical) is also used to carry out loss assessments; however, it is specific in that it complements or is based on secondary data, that is, data generated by the primary data collection or estimation approaches described above.

4.3.2 Groups of loss assessment approaches

Several loss assessment approaches can be identified, each serving a specific purpose. These approaches should be considered more as complements than as substitutes. These 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 analyse certain aspects related to PHL.

The main types of loss assessment methods are the following:

- **Rapid or initial assessments**. These are conducted to expose the most serious loss points. Data is generally collected using a combination of pilot or baseline surveys, based on relatively small random or purposive samples, focus groups and stakeholder workshops. Loss estimates generally rely on farmers' or actors' opinions (subjective measurement) and, in some cases, on the use of visual scales and objective measurements. They enable better comprehension of the post-harvest system and of the causes of losses. Additional information on the conditions of operation or farming, such as climate data (rainfall, temperature, etc.), can also be collected as part of these assessments. The outcome of these surveys is to provide initial loss estimates as well as indications on the main causes of losses. An example of this type of approach is given by the Rapid Loss Appraisal Tool (RLAT) developed by the Deustche *Gesellschaft für Internationale Zusammenarbeit* (GIZ).

- **Probability sample surveys**. The aim of these surveys is to obtain statistically representative loss data for relevant groupings, such as administrative and agro-ecological units (village, region, nation, etc.). Statistical representativeness is ensured by a sufficient sample size, an appropriate stratification scheme and a random selection of the units at all stages. The measurements can be objective – drawn from crop-cutting on the field or laboratory analysis of grain sampled from storage facilities – or subjective, by asking the respondent (farmer, storage facility manager, etc.) to provide his or her own estimate of loss. These operations are relatively expensive and time-consuming, and require well-trained personnel. These approaches may be referred to as in-depth assessments, because they are based on a statistically sound methodology and collect a more substantial body of quantitative information. Guidance on how to implement probability sample surveys for loss estimation is provided in chapter 5 of these Guidelines.
- **Experimental designs – field trials**. These assessments aim to quantify losses across different environmental conditions and farming practices, for instance traditional and improved agronomic practices. They are also used when equipment is to be tested for suitability to harvest, thresh, dry, or process commodities. Storage simulation trials can be conducted at research stations, exercising a high degree of control over the conditions of the experiment. At farm level, trials can be conducted for several objectives, including evaluating the effects of post-production practices on the level of losses. Although the design varies according to the study objectives and resources available, field trials are often based on relatively small samples of observational units (fields, for example) and involve physical measurements and laboratory analyses done over a defined period. These trials involve researchers and well-trained personnel that is capable of carrying out precise measurements and analyses. In agronomic literature, examples of such experiments abound. For a recent application on loss measurement, refer to Appiah, Guisse and Darty (2011), which carried out field trials to assess on-farm quantitative losses of different varieties of rice and for different farming practices. The use of experimental designs for loss assessment is addressed in chapter 6.
- **Modelling**. Loss assessment through modelling does not involve collecting data, but is rather an estimation or analytical technique aimed at producing loss estimates on the basis of different data sources, parameters and assumptions on the relationship between dependent variables (production, losses) and independent variables (climate conditions, crop variety, farming practices, etc.). The advantage of model-generated loss estimates is that they generally allow for identifying and quantifying the major determinants of commodity losses at different levels of the value chain. The models can rely on biophysical and climate relationships, linking losses to humidity levels, growing conditions, degree of pest infestation, etc. The models can also include variables characterizing the farm's activity (farm size, main crops, infrastructure available, etc.) and the household (farmer's experience in agriculture, income level, etc.), as well as external factors (beneficiary of extension services, etc.). These parameters can be calibrated (often in the case of biophysical models) or estimated using statistical inference (through a linear regression, for example). One of the main advantages of loss assessment models is their lower cost and their ability to predict losses in advance, such that planners and decision-makers can act appropriately and as early as possible in their decision cycles. The models require, however, sufficient data to be available from which parameters can be estimated. Model-based estimation is addressed in more detail in chapter 7.

Irrespective of the assessment method chosen, the results are only valid for the conditions under which they were conducted. Seasonal effects, which can only be detected after at least three years, affect the measured variables such as production levels and losses. Hence, the construction of a baseline requires conducting PHL assessments for at least three consecutive years, from which a solid average of losses in levels and percentages can be established.

4.4 PHYSICAL MEASUREMENT OF LOSSES: THE MAIN TECHNIQUES

Losses occur at all levels of the value chain, reflecting a variety of possible factors or causes. The methods and techniques used for measuring them will vary depending on the nature of the losses: caused by biodeterioration linked to climatic conditions (humidity, temperature, rainfall, etc.), pest infestation, spillage, scattering or other mechanical reasons including removal by birds, rodents, etc. Physical measurements described in this section can be used to assess the amounts lost because of these different causes.

4.4.1 Grain biodeterioration during storage

Grain biodeterioration may occur throughout the post-harvest system, mainly during the different phases of storage. Several techniques have been devised to measure weight losses due to biodeterioration for grains. Before describing them, the different points in the chain where storage loss may occur will be identified, along with the basic information that needs to be collected at each point.

Selecting and collecting data for the different chain actors

First, grain from the chain actors (farmer-producer, trader, processor or government warehouse, for example) must be accessed, such that a sample of it can be taken and further analysed. Because not all chain actors can be surveyed, a sample of them is usually taken. Discussions on sampling chain actors and their grain containers may be found in section 5.4.

Storage losses at farm level: Data on losses occurring during storage at the level of farm households will be collected periodically, for example every month, for a one-year period. The periodicity of the visits and the period during which they must take place depend on the storage practices for the crop, the region and the type of farm being considered. In some cases, crops will not be stored for longer than three to six months; in other circumstances, this period may be longer. The first visit should take place soon after the harvested grain is stored, ideally within one month. It is important to collect data on the moisture content of the grain at each visit, as this information is necessary to adjust weight losses for the losses due to drying. The information to be recorded thus covers the following components:

- Stock of produce at the beginning of the enquiry period
- Additions and retrievals to the stock during the enquiry period
- Total quantity stored
- Total quantity lost
- Moisture content of the produce
- Type of storage facilities
- Causes of losses

Storage losses off-farm (market, millers or processors, warehouses etc.): All selected market channels – wholesale or retail markets, milling or processing units, etc. – are completely enumerated in the area targeted by the study (entire country, selected administrative divisions within a region, etc.). Separate lists for wholesalers, retailers, and millers or processors are prepared. To reduce data collection costs, the survey can be based on a randomly selected representative sample of each market actor. The information to be recorded will cover the same items as those identified for on-farm storage.

In the case of millers or processors, losses will refer to the period starting from the commodity's entrance into the facility until immediately before processing. The periodicity of the data collection will vary depending on the type of actor surveyed and the average period during which the grain is stored. One visit per month is generally sufficient.

Loss measurement methods
Several techniques for measuring grain weight loss due to biodeterioration are available. Harris and Lindblad (1978), Boxall (1986) and Compton (1998) provide a comprehensive description of these techniques. These Guidelines suggest that the gravimetric or the Thousand Grain Mass methods constitute a good trade-off between measurement accuracy, applicability on the field and the associated implementation costs. These two methods are described below. The visual scales method, which combines qualitative and quantitative assessments, is also described here given its widespread use in loss assessments. Alternative methods are presented in annex 3.

Conventional Count and Weigh or Gravimetric Method.
Here, this method is illustrated for the determination of storage losses for maize. However, a similar process can be adopted for other grains.

1. A representative sample of cobs is taken from the maize store.

2. The sampled maize cobs are shelled and the resulting grains pooled together.

3. Two subsamples of 200–500 grains each are taken using a riffle divider. The grains in each subsample are separated by eye into two groups: damaged and undamaged. Separation of damaged from undamaged grains is discussed in Boxall (1986). The damaged and undamaged grains in each group are then counted and weighed.

4. Percentage weight losses are calculated separately for each subsample using the formula presented by Harris and Lindblad (1978):

$$\%\text{ weight loss} = \frac{(UNd) - (DNu)}{U(Nd+Nu)} * 100$$

Where:
- *U* is the weight of undamaged grain;
- *Nu* the number of undamaged grains;
- *D* the weight of damaged grains; and
- *Nd* the number of damaged grains.

5. In the final step, the average of the two subsamples is taken as the weight loss for the sample of cobs.

A further step may consist in adjusting the percentage weight loss to a given moisture content (for example, 14 percent). At minimum, the moisture content should be stated.

One of the drawbacks of this approach is that, for low infestation levels, it may give negative weight-loss figures. Variations of this formula have been proposed, such as the Modified Count and Weight Method.

Thousand Grain Mass Method (TGM)
This method was advocated by Boxall (1986) to determine losses arising during storage because of insects. It avoids some of the problems encountered with both the volumetric method (described in annex 3) and the count and weigh method. This method does not require knowledge of the weight at the beginning of the season. The standard TGM method is presented here[2].

A representative sample of grain is taken from the lot. To be considered representative, this sample should possess all of the characteristics of the grain stored at the time of sampling. The number of grains in the sample is recorded (*N*) and the sample is weighted to obtain its mass in wet basis (*m*). The TGM on a wet basis is equal to:

$$TGM_{wet} = m\frac{1000}{N}$$

The TGM on a dry basis is calculated using the following formula:

$$TGM_{dry} = TGM_{wet}.\frac{100 - H}{100}$$

Where *H* is the moisture content of the sample.

The dry weight of 1 000 grains is determined from a sample of grain collected at the beginning of the storage season (TGM_0) and compared with subsequent measurements throughout the season (TGM_t). The weight loss in a sample of grains between period 0 and *t* is given by:

$$\frac{TGM_0 - TGM_t}{TGM_0}\times 100$$

Visual Scales Method: Most of the techniques presented above and in annex 3 involve collecting grain samples from the farmers, sending them to laboratories for analysis and later returning them. This back-and-forth of grain samples delays the compilation of the loss estimates and the publication of the results of the surveys. Visual scales and standard charts (described in annex 3) allow for a rapid and relatively accurate determination of losses directly on the field or in the farm. Visual scales, which have been commonly used in loss assessments since their development in the 1990s (Compton *et al*., 1991), are presented here for the loss assessment of maize in cobs; however, they could also be applied to other grains or commodities, with some adaptations and variations. It usually involves the following steps.

Step 1: Different classes of pest infestation of maize cobs (scales) are defined. This is typically done by agricultural technicians by sorting and re-sorting a pile of insect-damaged maize cobs into visual classes, roughly reflecting the categories that farmers are used to, until a consensus is reached on the limits of each class. Table 1 provides an example of such classification.

2 Variations of this method have been proposed. Boxall (1986) provides details on these approaches.

TABLE 1. DESCRIPTION AND USE OF VISUAL SCALES IN EASTERN GHANA.

Class	Damage level	Description and use
1	Undamaged	For food or seed
2	Slight damage	A few infested grains. Always acceptable for food and usually mixed with Class 1. Sells at top price. May be used for seed after hand-cleaning.
3	Slight-moderate damage	Less than about half the cob infested. Acceptable to farmers and traders for mixing with Class 1 and 2, if in small proportion. Otherwise may be shelled selectively by hand, separating good from bad grains, or occasionally mixed with Class 4.
4	Moderate damage	More than about half the cob infested, but still with some areas of good grains on cob. Aceptable for human food by poorer groups and in lean seasons. Rarely mixed with good maize and only for immediate consuption. May be shelled selectively or mixed with Class 5.
5	Several damage	Over about 90% of the cob infested. Normally animal feed; used for human food only in time of scarcity, when it is mixed with higher grades. Still saleable in certain conditions, at low price.
6	Very severe damage	Cobs thrown away by farmer and unsaleable. Very little food value, even for animal feed.

Source: Compton, 1991.

Step 2: A weight loss parameter is associated with each class of pest infestation. These parameters are determined in advance of fieldwork by means of laboratory analyses using loss assessment techniques, such as the TGM or the gravimetric method.

Step 3: A visual print of the different classes and associated weight loss parameters is prepared and handed to the field teams that will carry out the assessment. An example of visual scale used in a PHL assessment study conducted in Malawi is provided below.

FIGURE 3. CLASSES OF PEST INFESTATION FOR MAIZE COBS.

Source: Malawi, 2011.

Step 4: For each storage facility selected (on- or off-farm), the enumerator takes a sample of cobs and matches the cobs with the various classes of infested cobs portrayed in the pictures. The enumerator determines the number of cobs assigned to each class.

Step 5: The weight loss for any given unit (farm, village, enumeration area, etc.) is calculated by taking an average of the weight loss parameters recorded (W_1, W_2, W_3, etc.) weighted by the share of the cobs in each class in the total number of cobs sampled ($^{N_1}/_{N_T}$, $^{N_2}/_{N_T}$, $^{N_3}/_{N_T}$, etc.).

4.4.2 Mechanical damage, grain scattering and spillage for traditional (manual) farming

While biodeterioration generally occurs during storage, losses due to mechanical damage, scattering or spillage are characteristics of the different post-production operations, from harvest to processing. Physical measurement techniques for each of these stages are described below. These methods are relevant for farming operations mostly done manually, as is still the case in the traditional sector in developing countries. Measurement methods for mechanical processes are provided in section 4.4.3.

In this section, the full range of operations that may be performed on the farm for grains is considered. In practice, depending on the typical farming practices in the country or region of interest, some may be irrelevant or insignificant and therefore discarded from the assessment. For example, the practice of stacking or stooking may not be common, or the processing or milling of grains may be mainly carried out by service providers outside the farm, justifying its exclusion from on-farm loss measurements. For cost-efficiency purposes, these Guidelines recommend that studies targeting traditional farming focus on the following operations (in addition to storage, addressed in section 4.4.1.): harvesting, threshing or shelling, cleaning or winnowing, drying, and transport. In this section, for consistency purposes, we describe the full range of operations in their typical chronological order.

Losses during harvesting. The measurement of harvest losses would benefit from a linkage with an annual production survey that has a crop-cutting component. This subsection describes a possible approach to assess harvest losses using physical measurements. Some of these operations may already be included in the production survey:

Step 1: Crop-cutting plots (subplots) are placed at random in each selected field before harvesting by the holder. Two subplots in a field can be placed if time and resources allow. If only one subplot is placed, a sufficiently large sample of fields for each targeted crop needs to be selected to allow for sufficient observations. The size of the subplots varies according to the crop and local practices. For cereals, typical sizes are 10 m x 5 m, 5 m x 5 m, or smaller for crops with higher densities such as rice. There are several ways to place a subplot of a given shape and dimension in a field. A possible method is provided in box 1 below.

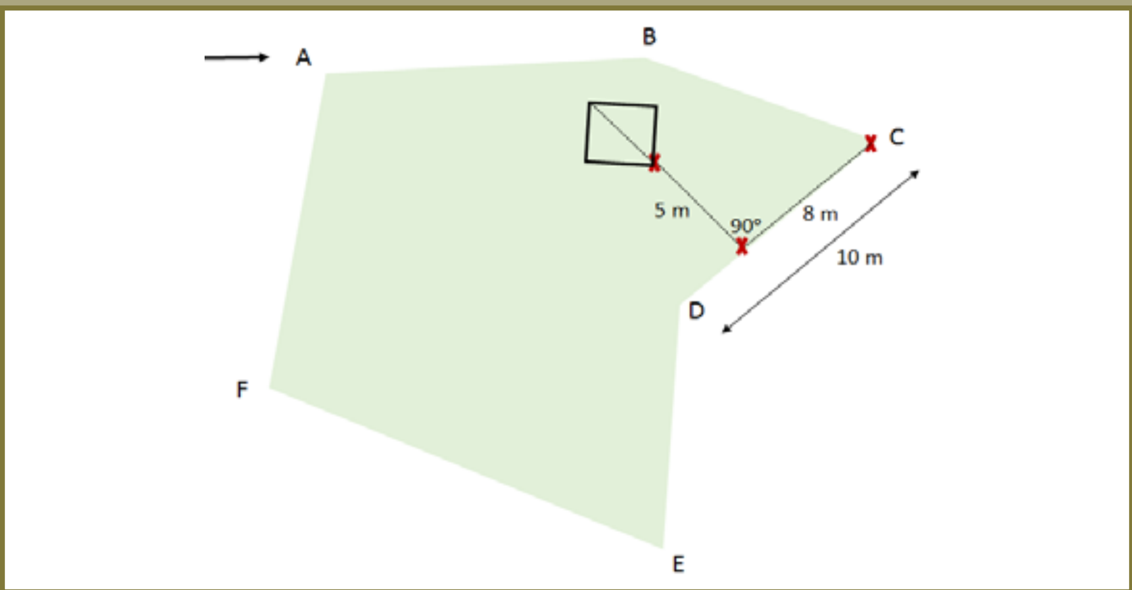
BOX 1. RANDOM PLACEMENT OF A SUBPLOT IN A FIELD FOR CROP-CUTTING.

The method of placement of a subplot described here is provided for illustration purposes and should not be considered as the only recommended approach. Several other approaches exist, which may be more suitable to local conditions, survey practices and the specific objectives of each survey. The approach presented here was used in a pilot-survey conducted in 2016–2017 by the Global Strategy in Ghana. It comprises the following steps:

1. Localization of the field, identification and numbering of all its points or vertices.
2. Measurement of the length of each side, ideally using an adapted GPS device. Computation of the perimeter, area and half-perimeter of the field.
3. Selection of a first random number between 1 and the number of vertices or sides of the field (a random number table can be used for this and other random draws). This first random number will determine the vertex (point) and side from which the enumerator will go inside the field. The enumerator goes to the chosen point or side walking clockwise from the entry point.
4. Selection of a second random number between 1 and the length of the selected side. The random number gives the distance from the point from which the enumerator will enter the field.
5. Selection of a third and final random number between 1 and the half-perimeter of the field, to determine how far, perpendicularly from the side, the enumerator will go into the field. The enumerator marks the point reached in the field with a peg: this will be the first point of the subplot.
6. The subplot of the desired size can now be placed using pegs and ropes: from the first peg, a second enumerator will walk in the same direction until he reaches the opposite point of the diagonal. For example, if a 6 m x 6m subplot is used, the diagonal should be 8.485 m. A rope of the length of the diagonal can be used to facilitate the placement of the subplot.

This procedure might lead to select a subplot falling wholly or partially outside the bounds of the field. In this case, the procedure described in step 3 should be repeated. The placement procedure is illustrated in figure 4 below:

FIGURE 4. EXAMPLE OF PROCEDURE FOR THE RANDOM PLACEMENT OF A YIELDING PLOT



Step 2: As soon as the crop is ripe and some time before the holder starts harvesting the field, the team of enumerators picks up grains, ears or cobs on the ground from the subplots placed for crop-cutting. This amount will be weighted and recorded as the amount of pre-harvest losses.

Step 3: The subplots are then harvested according to the usual farmer practices and the yield is weighted and recorded.

Step 4: After the harvested produce is removed from the subplot, all grains shed or missed, as well as all cobs and ears remaining on the ground, are collected and weighted. This quantity will be used to estimate the losses during harvest for this subplot.

The information related to steps 3 and 4 is recorded by the enumerators in survey questionnaires. Figure 5 provides an example of table used to record information on yields and losses from a crop-cutting plot. This table was used in a pilot survey on the measurement of PHL carried out in Ghana in 2016–2017.

FIGURE 5. RECORDING CROP-CUTTING MEASUREMENTS.

B. Losses during harvesting

Method of Harvesting: [ ] 25 — 1. Manual 2. Mechanical

Date of Harvesting: ...../...../2016

YieldingPlotNo	Random		Crop	During manual harvesting of yielding plot				After manual harvesting : Grains/Cobs fallen of yielding plot						
	Second	Third		Ears / Cobs	Raw Weight	Dry Weight	Kg/Ha (Office Use)	Ears / Cobs	Raw Weight	Dry Weight	Kg/Ha (Office Use)	Grains	Raw Weight	Dry Weight
26	27 28 29 30	31 32 33 34	35	36 37 38 39	40 41 42 43 44	45 46 47 48 49	50 51 52 53	54 55 56 57	58 59 60 61 62	63 64 65 66 67	68 69 70 71	72 73 74 75	76 77 78 79 80	81 82 83 84 85

Observation (for moisture content) : ------------------------

C. Losses during threshing/shelling

Source: GSARS, 2017a.

The crop-cutting operations require adapted equipment and material. For each field team, ideally composed of experienced enumerators or supervisors, the minimum requirements are the following:

- Measuring tape
- Solid demarcating tool
- Shears, knives and sickles
- Bags for the harvested crops, as used by the farmer
- Portable weighing scales
- Rolls of string
- Moisture metres

One of the many risks of bias in the measurement of losses during harvest derives from the fact that the harvesting may not be carried out using the farmer's practices. If the operations are performed by the farmer or farm labourers, they might perceive the situation as being a not 'normal' one and hence attempt to harvest the crop-cutting plot and handle the bundles differently from the practice usually followed, typically with more care. If the operations are carried out by enumerators, they may not use the actual farmer's practice but rather a recommended approach. These limitations apply equally to other farm operations (threshing, etc.) and constitute the major challenge associated with physical measurements.

While the losses occurring during harvest are estimated from the yield obtained from the crop-cutting plot, it is recommended that the estimation of losses for the various post-harvest stages be assessed on the basis of a sample of the farm's total produce. Indeed, measurements based on small quantities of produce are likely to lead to an underestimation of losses: small quantities are easier to handle and the enumerators are more likely to be excessively cautious when performing the different operations rather than when using the actual farmer's practice.

Losses during stacking or stooking. The practice of stacking or stooking[3] crops is common in many developing countries and serves to bring the crops to the appropriate moisture content. A possible measurement method comprises the following operations. First, a sample of the stacks is randomly selected in the farm's fields. Second, when the stacks are removed, after a time consistent with the farmer's practices, the scattered grains are collected, put into plastic bags and weighted. Third, the percentage loss is calculated as the ratio between the amount lost and the quantity of grain obtained after threshing the selected stacks, adjusting for differences in moisture content if the threshing is done well after the removal of the stacks.

This approach can be affected by several biases:

- As stooks are generally left in the open, weather conditions (temperature, humidity, rainfall, etc.) affect grain quality: these may result in weight losses if grain is rejected as unfit for human consumption or if the damage to the grain leads to a loss in weight. To capture these losses, a sample of grains, cobs or ears taken just before stooking can be contrasted with a sample taken just before threshing to assess grain damage and associated losses. This requires sending samples to a laboratory for analysis, as is done for storage loss assessments.
- Second, if grain remains stacked or stooked for many months, this can be regarded as a means of storage during which losses to rodents, birds, insects and other pests may occur. Hence, the standard techniques for estimating losses due to insects during storage can be applied (grain samples taken at the beginning and at the end of the stooking period, laboratory analysis). Losses due to birds and rodents are always difficult to estimate. The weigh-in and weigh-out method could however be used, correcting for differences in moisture content and for the losses due to scattering.

Losses during threshing or shelling. A standard method for measuring losses during threshing or shelling is the following.

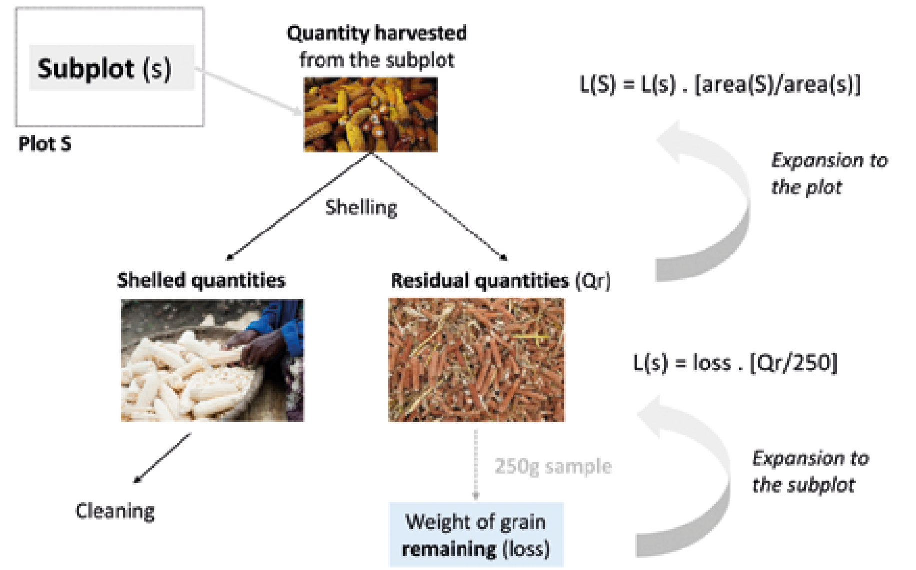
Step 1: A sample of the farm's harvested produce – for example, 50 kg to 100 kg – is randomly selected and threshed according to the farmer's practices. Although manual threshing is still common in developing countries, it is progressively being replaced by mechanical threshing. The threshing can occur immediately after harvesting or after a drying period, depending on the farmer's usual practice. The grain after threshing is collected and weighted. The residual straw is also collected and weighted.

Step 2: The remaining straw is carefully examined for grains remaining in it. To do this, a sample of straw is usually taken – for example, of 1 kg to 5 kg – depending on the crop. In this sample, the remaining grains are collected, counted and weighted. To improve the robustness of the estimates, several samples can be taken and an average over the different samples of grain weight remaining in the straw recorded.

Step 3: This quantity is then expanded to the total quantity of straw obtained from the threshing of the 50 kg – 100 kg sample of produce and divided by the quantity of produce brought to threshing: this is the estimate of percentage losses at threshing. The overall measurement process is illustrated in figure 6.

3 In this paragraph, the terms stacking and stooking (as well as stacks and stooks) are used indifferently.

FIGURE 6. ILLUSTRATION OF THE MEASUREMENT PROCESS.



All of the information collected (number of bundles threshed, weight of grain after threshing, weight of straw, number and weight of grain remaining in the straw, etc.) should be recorded in survey forms, such as that presented in figure 7.

FIGURE 7. RECORDING LOSS MEASUREMENTS DURING THRESHING OR SHELLING (EXAMPLE).

C. Losses during threshing/shelling

Method of Threshing/shelling: |__| 86 1. Manual 2. Mechanical **All weight in grams** **Type Threshing floor:** 0. Unknown 1. Mud 2. Wooden 3. Cement

Date of Threshing/shelling: ...../...../2016

Type of threshing/shelling floor	Number of bundles from yielding plot	Weight of grain after threshing/shelling bundles	Weight of straw obtained	Weight in 250g of straw	Number of grains in 250g of straw
87	88 89	90 91 92 93	94 95 96 97	98 99 100 101	102 103 104 105

Source: GSARS, 2017a.

This measurement method is appropriate both for manual processes as well as for losses incurred using mechanical threshers or shellers. However, this method does not take into account two types of losses that may occur during the threshing: losses due to scattering and spillage on the threshing floor and those due to damaged grain, significant sources of losses when using mechanical processes.

For losses due to scattering and spillage, there is little guidance in the literature on ways to assess them. Some researchers suggested spreading a large sheet on the threshing floor to capture all possible scattered grains. However, this might be difficult to achieve in practice especially if the area to cover is large, as grains can be scattered several metres from the point of threshing.

Losses related to grain damage caused by the shelling method may be significant, especially if mechanical processes are used. Measuring these losses is necessary to obtain a complete view of on-farm grain losses and to provide an indication of the efficiency of the threshing or shelling method. The measurement can be done by selecting a sample of grains obtained after the threshing process (200 grains, in the case of maize, for example). The grains are then bagged and sent to a laboratory for analysis using the count and weigh methods previously presented. From these parameters, an estimate of the percentage grain loss due to damage during threshing or shelling can be obtained.

Losses during cleaning or winnowing. The process for estimating grain losses during manual winnowing operations is analogous to the method used to determine threshing losses:

Step 1: The grain obtained after threshing the sample of harvested crop (see figure 6) is winnowed according to the practice used by the farmer. The output of this process will be an amount of clean grain and a residual amount of chaff (husks, plant material, stones, etc.). Both amounts are weighted.

Step 2: The chaff is carefully examined for remaining grains. To do this, a sample of chaff is usually taken, for example of approximately 500 g to 1 kg. In this sample, the remaining grains are collected, counted and weighted. To improve the robustness of the estimates, several samples can be taken and an average over the different samples of grain weight remaining in the chaff recorded.

Step 3: This quantity is expanded to the total chaff resulting after the winnowing process and divided by the total amount of grain cleaned: this is the measure of percentage losses during winnowing.

The data collected is recorded on survey forms similar to the one presented for threshing (see figure 7 above).

This measurement method is adapted to capture the losses occurring because of part of the edible grain passing into the chaff. However, additional losses may occur due to the scattering of the grains on the cleaning floor. To measure these losses, the winnowing operations may be done on a plastic or tarpaulin sheet and the fallen grain after the process collected and weighted. However, as for threshing, this might be difficult to achieve in practice as grains can be scattered several metres from the point of cleaning.

Starting from the drying phase, these Guidelines recommend carrying out loss assessments on the basis of the usual quantities of crop handled by the farm (bulk handling), instead of relying on the amounts harvested from the crop-cutting plot or from a sample of harvested produce, as is done for the previous operations. Indeed, handling small quantities of produce is easier and likely to lead to lower percentage losses than when larger quantities are involved.

Losses during drying. To estimate losses at this stage, the following information needs to be collected:
- The quantity of grain initially spread out for drying (weigh-in)
- The moisture content of the grain immediately before drying
- The quantity of grain collected after drying (weigh-out)
- The moisture content of the grain collected immediately after drying

The weight loss during drying is calculated by the difference in weights between the start and the end of the drying period (weigh-in minus weight-out), corrected for variations in moisture content. The reduction in weight due to the lowering of the moisture content is therefore not accounted for as a loss.

Losses during transport. Losses can occur on the farm when transporting the crop from the field to the threshing floor and from there to the storage. Losses can also occur off-farm, for example during transportation from storage to the market. Losses are normally estimated as the difference in weight between the quantities loaded (weigh-in) and unloaded (weight-out). The following information must therefore be collected:
- The quantity of grain initially loaded onto the vehicle (weigh-in)
- The quantity of grain unloaded from the vehicle, having reached the dropping point (weight-out)

For long transport operations taking several days or more, the moisture content also needs to be measured at the loading and unloading points, so that appropriate corrections for changes in moisture content can be made. Grain can also suffer damage due to pest infestation, as it usually does during any storage period. To assess qualitative losses during transit, samples of grain can be taken at the loading and unloading stages and sent to a laboratory for analysis. The quantitative losses due to pest infestation should be properly captured by the weigh-in and weigh-out method.

Losses during processing. Processing losses can happen on or off the farm, depending on the structure of the value chain, and can be the result of a manual process (for example, hand-pounding) or mechanical process (such as rice milling using hulling machines). Several processing operations can be carried out depending on the crop and the practices. Typical operations involve dehusking, milling and grinding of grains.

Here, quantitative losses are especially difficult to assess, as the grain generally changes nature and form from one process to another. Hence, the weigh-in and weigh-out method, in which the grain is weighed when it enters the process and when it comes out of it, may not be the most suitable. Consider the example of rice milling, where the objective is to remove the husk and bran of the paddy to obtain white rice that is sufficiently milled and free of impurities. Most of the reduction in weight due to processing cannot be accounted for as food loss, as the loss is due to the removal of inedible husk and bran (approximately 30 percent of rice is composed of husk and bran). Further, the loss depends on the characteristics of the final product: the production of brown rice, for example, requires less milling, as the bran layers are not removed. For these reasons, losses at the processing stage are often measured as qualitative losses. An example of qualitative loss at processing is the percentage of broken kernels resulting from the milling process, as compared to a benchmark for a given variety, for example.

Losses due to scattering and spilling during processing stages can be measured by collecting and weighting the grains remaining on the ground. These losses are more significant for manual or mechanical processing at farm or village level than in specialized off-farm processing units.

Assessing losses occurring during processing is a complex and time-consuming operation. To contain survey and study costs, loss assessments at the processing stage could focus on the storage phase in processing units and exclude the losses incurred during milling, etc. Another reason for excluding such losses is that when grains are processed into flour or other products, this process is no longer part of the grain value chain in strict terms, but rather of the value chain of another product (flour, etc.)

Losses during packaging. Losses occurring due to defects in the methods of packaging and handling of grains can also be estimated. These are mainly caused by scattering and shedding of the grain as well as damages (which may or may not be linked to pest infestation) resulting from improper packaging or handling. However, losses at this stage are generally not significant compared to those occurring at other points of the post-harvest value chain, and can therefore be ignored. Moreover, packaging losses are confounded to some extent with other types of losses, such as losses arising during storage or transport, and are therefore difficult to isolate.

4.4.3 Mechanical damage, grain scattering and spillage for farms using combine harvesters

Introduction and sources of losses. On-farm harvest operations involve several operations, such as crop-cutting, gathering or bundling, transport, threshing, separation, and cleaning. For crops, one of the most important operations is the threshing phase, which consists in removing the grain, oilseed, or pulse kernels from the rest of the crop material that initially stood in the field. For small grains such as rice, the first step involves cutting plant stems close enough to the ground to obtain all pods or panicles containing seeds. For large grains such as maize, ears are pulled with a bending or twisting action away from the stalk of the plant. Harvest and immediate post-harvest operations may be manual, involving the use of large amounts of labour, partly mechanized, or fully mechanized, as is the case when using combine harvesters (see figure 8). A technical description of the different operations carried out by combine harvesters is provided in annex 4 to these Guidelines. Losses due to damage and spillage occur during these operations and their entity depends on the type of harvester and a range of characteristics pertaining to the crop and harvesting conditions.

FIGURE 8. COMBINE HARVESTER.

Source: https://commons.wikimedia.org/w/index.php?curid=373633.

Estimation of losses. The estimation of losses associated with the use of combine harvesters typically involves relatively complex and lengthy experimental designs on small samples of fields. The methods vary in sophistication, especially regarding design and sample selection, but usually involve:

- Estimating pre-harvest losses for any given field by setting up at least two randomly selected crop-cutting plots (for example 5 m x 5 m) and collecting the grains that have fallen in these plots prior to the start of harvesting;
- Harvesting the whole field with the combine harvester;
- After harvesting, setting up two new randomly selected crop-cutting plots and collecting all grain that has fallen in these plots and remaining on stalks.

The difference between the grain weights recorded after and before harvesting is an estimate of the quantity of grain losses at harvesting. The measurement methods are further detailed and illustrated in the two case studies presented in boxes 2 and 3.

BOX 2. EVALUATING RICE LOSSES FOR VARIOUS HARVESTING PRACTICES (ALIZADEH AND ALLAMEH, 2013).

The evaluation described below is based on a controlled experiment. Given its level of detail and complexity, this type of study design is not implementable on a large scale in nationwide surveys. It is presented here because it illustrates well how losses occurring during mechanical harvesting can be measured in practice. The same observation is also valid for the experiment described in box 3.

The performances of five different harvesting methods were assessed using a Randomized Complete Block Design (RCBD) with four replications: hand cutting + threshing by a tractor driven thresher (T1); rice reaper + threshing by a tractor driven thresher (T2); rice reaper + threshing by universal combine harvester equipped with pickup type header (T3); head-feed rice combine (T4); and whole-crop rice combine (T5). T1, T2 and T3 were qualified as indirect harvesting methods while T4 and T5 were qualified as direct harvesting methods. In indirect harvesting, cut paddy stalks were left across the field for approximately 24 hours to reduce moisture content and then gathered and threshed by a tractor-driven thresher. In direct harvesting, harvesting and threshing took place in quick succession.

Before operating, crop conditions were measured in terms of plant height, number of hills per unit area, grain-separating force from panicle, and moisture content. For additional details regarding the different preliminary physical measurements, refer to Alizadeh and Allameh (2013).

Harvest losses (T4 and T5): To determine quantitative loss before and after harvesting through manual cutting and reaper harvester, a 1 m × 1 m wooden frame was thrown randomly over four spots in each plot. The grains inside the frame were gathered and weighted. In combine harvesters, losses are observed at two main points: at cutting (in front) and threshing (at the back). To capture these losses, the wooden frame was thrown ahead and to the back of the combine, and all grains and panicles inside it gathered and weighted. The percentage weight loss at treshing is computed by the following formula:

$$HL = [\ (L1 - L0)\ / Y\ ] * 100$$

Where HL is the percentage harvest loss, L1 is the grain weight loss recorded after harvest, L0 is the grain weight loss before harvest and Y the grain yield. L1, L0 and Y must be expressed in the same units, such as kg.

Threshing losses (T1, T2 and T3): A wide plastic sheet was spread over a flat surface and a thresher settled on it. In experiments, the threshing chamber was fed uniformly. Afterwards, all grains and panicles on the plastic sheet were gathered and weighted. The percentage weight loss at harvest is computed by the following formula:

$$TL = [\ L/(T+L)\ ] * 100$$

Where TL is the threshing loss on %, L the weight of grains thrown out of different parts of the thresher and T the weight of grains collected of the main outlet.

Percentage of broken and husked grains: Four samples of 100 g of rough rice were taken from the outlet of the thresher and the rice combine harvester and then broken. Husked grains were separated manually and weighted.

Average quantitative losses were found to be 2.6 percent and 2.3 percent for indirect harvesting (treatments T1, T2, and T3) and direct harvesting (treatments T4 and T5), respectively. In indirect harvesting, losses on cutting and gathering were higher than those arising during threshing. A more detailed description of the results and statistical analysis is provided by Alizadeh and Allameh (2013).

BOX 3. MEASUREMENT OF COMBINE LOSSES FOR CORN AND SOYBEANS IN BRAZIL (PAULSEN *et al.*, 2013).

The objectives of the study were to determine: (1) the total harvest losses for a sample of combines harvesting corn and soybean in some of the major growing regions of Brazil; and (2) the magnitude and variability of components of total loss for these combines, including pre-harvest, gathering, threshing and separating losses. Combine harvest losses were measured using the Embrapa method, described by Mesquita *et al*. (1998), and by the procedure described in Shay *et al*. (1993a) and Kulkarni (2013). The main elements of the measurement approach are as follows.

Step 1: Measurement of pre-harvest losses in an area of 2.0 m^2 of standing crop.

Step 2: Measurement of the total losses behind the combine after it was running in the field at full capacity and at normal operating speed. This loss was measured across the full width of the combine header in a rectangular pattern of sufficient length to provide an area of 2.0 m^2. All loose beans and beans in loose pods on the ground were picked up, as well as any beans in pods still attached to stalks. This quantity was placed in a plastic bag, labelled and taken to the lab for weighing and moisture adjustment.

Step 3: The combine loss was calculated by subtracting the pre-harvest loss from the total loss, similarly to the approach used in the previous case study (box 2). Soybean combine losses can be further broken down into total header loss (gathering unit) and threshing/separation losses. To obtain header losses, the combine was operated at full capacity and normal speed and stopped suddenly. The separator was given time to clean out, then the combine was backed up by a distance of approximately 4 m. An area of 2.0 m^2 was laid out the full width of the header but within the 1 m to 3 m space where the combine was located when its forward motion stopped. Thus, this area did not have crop material deposited on it. Therefore, the only losses present would be due to the header plus any pre-harvest losses.

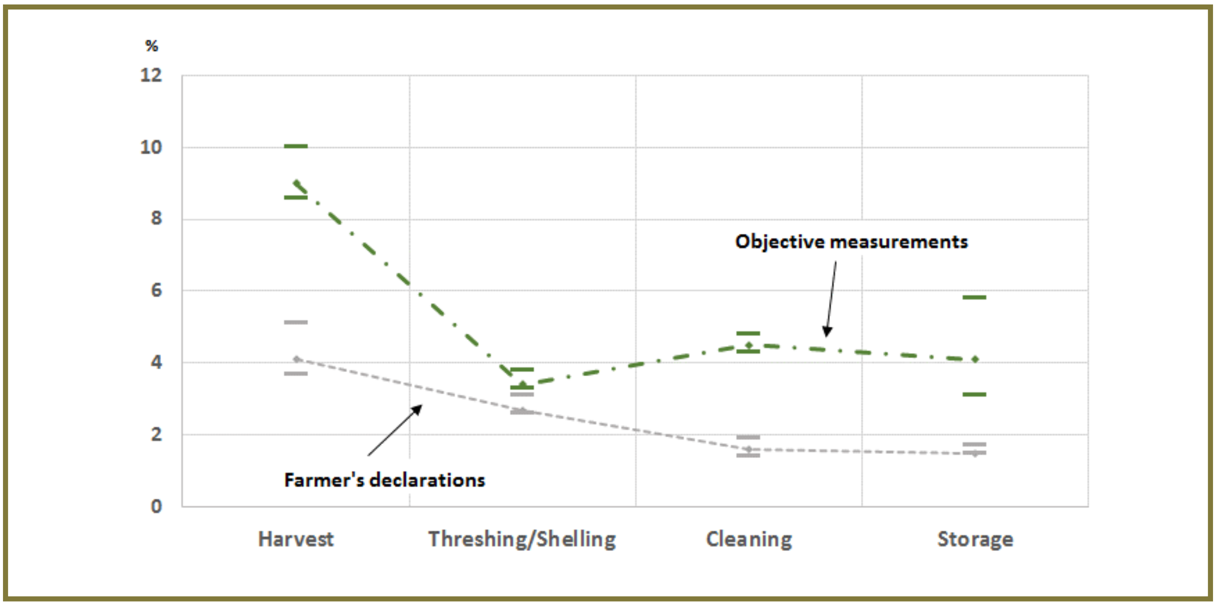
Using this approach, pre-harvest losses for soybean were estimated from 1.0 kg/ha to 13.6 kg/ha and total soybean combine losses from 47.4 kg/ha to 260.5 kg/ha (1.2 percent to 5.5 percent of yield). For corn, pre-harvest ear losses ranged from 0 kg/ha to 42 kg/ha and total combine losses from 36.2 kg/ha to 320.6 kg/ha (0.3 percent to 3.6 percent of yield). Complete results are provided by Paulsen *et al.* (2013).

4.5 MEASURING LOSSES THROUGH FARMER DECLARATIONS

4.5.1 Introduction and rationale

In addition to physical measurements, losses can also be assessed by directly asking the farmer about the losses experienced during the different stages of the crop's production process. This approach has been defined as subjective, because it is based on farmer opinion and not on objective (physical) measurements made on the field. Estimates coming from subjective methods may be affected by a declarative bias, because the farmer may lack knowledge on his or her losses or because of the reliance to give accurate information. This may be true in certain circumstances, such as during harvest, when it is particularly difficult for the farmer to assess losses. Relatively few studies have compared objective and subjective methods for loss measurement. As part of the Global Strategy's research activities on PHL, a pilot survey was undertaken in Ghana to test the feasibility of survey-based objective and subjective methods for loss measurement (GSARS, 2017a). One of the findings of this pilot survey is that objective measurements generally lead to higher loss estimates than farmer declarations (figure 9).

FIGURE 9. MAIZE LOSSES: FARMER-REPORTED VERSUS OBJECTIVE MEASUREMENTS, BY OPERATION (%, ALL DISTRICTS).



Source: GSARS, 2017a.

The main advantage of the farmer declaration approach is that it is considerably less time-consuming and expensive than physical measurements. It should therefore be part of any loss assessment strategy, especially if it is combined with and completed by other measurement methods. For example, a proper benchmark and adjustment factors can be determined for a given year by measuring losses using both farmer declarations and physical measurements. These adjustment factors can then be used to correct farmer declarations obtained from lighter annual surveys to improve the estimation of losses, until a new in-depth assessment involving physical measures is carried out and new benchmarks and adjustment factors are set. Additional details on this adjustment procedure, which can be more or less sophisticated, are given in chapter 7 on modelling.

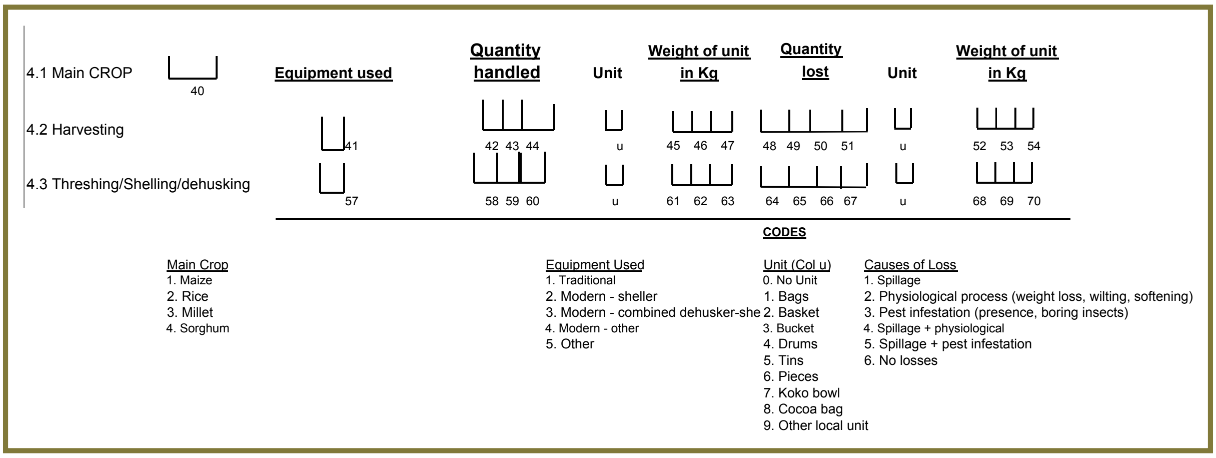
The next paragraph presents different ways to ask farmers for an estimate of losses experienced on the farm, as well as the advantages and limitations of each approach. Storage losses are distinguished from other types of losses because of their specificity in terms of measurement.

4.5.2 Farmers' estimates for harvest and post-harvest operations

There are different ways to obtain from farmers an estimation of losses for different farm operations. The methods can be classified into two broad categories: (i) relative approaches, in which the farmer is asked to provide an estimate of losses relative to a benchmark; and (ii) absolute approaches, in which the farmer is asked to provide the total quantities lost directly. Irrespective of the approach chosen, the quantity handled at the beginning or at the end of each process (harvesting, threshing, etc.) must be determined so that the quantities lost, in percentage and absolute terms, can be worked out.

Absolute (or direct) approach. The absolute or direct approach consists in asking the farmer directly for an estimate of the weight loss for the different operations. This approach assumes that the farmer has a good knowledge of the overall quantitative losses for each operation. The farmer may find it difficult to reply directly in terms of standard units, such as kg, especially if the storage, handling or selling of the produce is expressed in non-standard units (bags, etc.). In addition, as the quantities lost will be considerably smaller than the quantities handled, it may be relevant to allow the farmer to provide different units for quantities handled and quantities lost. For example, the farmer may state that he has shelled 10 bags of 100 kg of maize and that he lost a grain amount equivalent to four bowls each weighing 2.5 kg. Figure 10 provides an example of a module asking farmers to provide the quantities handled and lost.

FIGURE 10. HARVEST LOSSES ESTIMATED BY THE FARMER.



Source: GSARS, 2017a.

Relative approach. For each process, except harvest and storage, for which losses need to be estimated, the farmer is asked to provide an estimate of the proportion lost at each stage. The advantage of this approach is that it facilitates farmer reporting by giving them a reference or benchmark, instead of asking them directly for the total quantities lost. It is important to provide a meaningful benchmark for each operation. For example, if the question to measure relative losses during cleaning or winnowing is "Out of 100 units brought to cleaning/winnowing, how much do you think you lost?", it is important to ensure that the number of units provided as reference (100) is relevant for this specific operation. If the farmers tend to use a smaller number of larger units, then a smaller benchmark (20, 50, etc.) can be used. It is also important to ensure that the unit referred to in the question is the same as that used to report the quantities cleaned/winnowed, or at least that the two can be related so that a quantitative loss estimate can be provided. Figure 11 provides an example of questionnaire module used to assess cleaning/winnowing losses using a relative approach. The procedure is slightly different when asking about losses during threshing, as the produce is transformed from ear or cob to grains. The unit at the beginning of the process being different from the unit at the end of it, asking for the proportion would not be meaningful. Instead, it is necessary to ask for the weight loss (kg) undergone by the unit taken as a reference (bundle, bag, etc.). This is illustrated in figure 12.

FIGURE 11. CLEANING/WINNOWING LOSSES ESTIMATED BY THE FARMER.

D3) Cleaning/Winnowing		
D3-1) Did you clean/winnow your harvest? (if No -> go to D4)		|____|
If yes:		
D3-2) What cleaning/winnowing method was used?		|____|
	Number of units	**Unit type**
D3-3) What was the quantity brought to cleaning/winnowing?	|______|	|____|
D3-4) What is the weight of this unit in Kg?		|______|
D3-5) Out of 10 units, how many do you think you lost during cleaning/winnowing? (using the unit reported in D3-3, decimals are allowed)		|______|
D3-6) What are the three main causes of losses during cleaning/winnowing?		|___||___||___|

FIGURE 12. THRESHING/SHELLING LOSSES ESTIMATED BY THE FARMER.

D2) Threshing/Shelling		
D2-1) Did you thresh/shell your harvest? (if No -> go to D3)		|___|
If yes:		
D2-1-b) Is threshing/shelling and cleaning/winnowing done in one step?		|___|
D2-2) What was the threshing/shelling method used ?		|____|
	Number of units	**Unit type**
D2-3) What was the quantity brought to threshing/shelling?	|______|	|____|
D2-4) What is the equivalent in Kg of the unit?		|______|
D2-5) Out of 1 unit, how many Kgs of grain do you think you lost during threshing/shelling? (using the unit reported in D2-3, decimals are allowed)		|______|
D2-6) What are the three main causes of losses during threshing/shelling?		|___||___||___|

4.5.3 Farmers' estimates of storage losses

The estimation of losses during storage using farmer declarations is a relatively complex undertaking, as it requires the farmer to have precise knowledge on the quantities of produce stored, and on the quantities that have left and entered the storage unit. The difficulty in estimating storage losses at the farm level also resides in the fact that at a given point in time, the quantities in store may come from a different harvest (for example, residual quantities from a past harvest) or from outside the farm (purchase of grain of the market, storage of grain from a neighbouring farmer, etc.). It may therefore be challenging to associate the storage loss to a specific harvest or batch, or even to a given farm. The reference period must be clearly specified to reduce the risk of bias in the results. Several measurement options are presented below, from the simplest (but probably less precise) to the more sophisticated. The timing of the survey is also important: the assessment can be done in several visits or in one visit. In the latter case, the timing of the visit is key: if the enumerator comes too early, the loss will be underestimated; if it comes too late, it will be more difficult for the farmer to recall the information.

Direct approach. This consists in directly asking the farmer for an estimate of the quantities lost during storage over a specific period or for a given harvest, if possible allowing for responses in non-standard units to facilitate reporting. Figure 13 provides an illustration of this approach, used for a pilot survey in Ghana. The advantage of this approach lies in its simplicity. Its main disadvantage is its lack of precision, which may lead to biased results. The farmer needs to recall and report the quantities lost related only to the produce coming from his own harvest, which may be difficult if crops coming from several farms or different sources are stored at the same time on the farm. In some cases, the produce from different harvests, farms or sources may even be mixed in a granary, which adds further complexities. If the quantities lost from the farmer's own harvest cannot be properly identified, it will not be possible to relate these to the quantities stored, thus impeding the measurement of percentage losses. The indirect (or difference) approach, which determines losses by deduction or difference, can also be used to limit the risk of bias. This approach is described below.

FIGURE 13. STORAGE LOSSES ESTIMATED BY THE FARMER – DIRECT APPROACH.

4.7 Storage

Storage type								
121	122 123 124	u	125 126 127	128 129 130 131	u	132 133 134	135	136

CODES

Main Crop	Storage Type (Col 111)	Equipment Used	Unit (Col u)	Causes of Loss	Harvest period
1. Maize	1. Silos	1. Traditional	0. No Unit	1. Spillage	1. Past
2. Rice	2. Granaries	2. Modern - sheller	1. Bags	2. Physiological process (weight loss, wilting, softenin	2. Current
3. Millet	3. Pots	3. Modern - combined dehusker-she	2. Basket	3. Pest infestation (presence, boring insects)	
4. Sorghum	4. Cribs/barns	4. Modern - other	3. Bucket	4. Spillage + physiological	
	5. Room storage	5. Other	4. Drums	5. Spillage + pest infestation	
	6. Heaped on ground		5. Tins	6. No losses	
	7. Other		6. Pieces		
			7. Koko bowl		
			8. Cocoa bag		
			9. Other local unit		

Source: GSARS, 2017a.

Indirect (or difference) approach. This approach consists in carrying out a complete assessment of the stocks related to the past agricultural season that, by deduction, will yield estimates of quantities lost during storage. If the objective is to measure farm-level storage losses, this assessment must refer to the crops harvested and stored on the farm during the period of analysis. The assessment consists in determining how much of the past harvest of a given crop was stored on the farm, what quantities exited the farm through selling, gift or own-consumption during the reference period, and how much currently (at the time of interview) remains on the farm. The difference between the quantities initially stored, on the one hand, and the quantities sold, used and remaining, on the other hand, provides an estimate of the losses occurring during storage. Figure 14 provides an example of the questionnaire used to record the information. To yield meaningful results, this approach assumes that the farmer recalls precisely the amounts harvested, stored and used, which may be a strong assumption especially if the data refers to the past harvest. The unit is also key: the reporting unit with which the farmer feels more comfortable should be used. Different units may be used depending on the nature of the phenomena: the harvesting or storage unit may be different from the unit chosen to report the amounts used for the household's own consumption, for example. This indirect approach can also be used to assess losses occurring during the current agricultural season. In this case, several periodic visits should be made to the holding to assess losses over time. This will facilitate the farmers' reporting and contribute to more accurate and precise results.

FIGURE 14. STORAGE LOSSES ESTIMATED BY THE FARMER – INDIRECT APPROACH.

E1-1) How much did you store from the past harvest (in Kg)?	|____|.|__|
E1-2) What is the storage type for this crop?	|____|
E1-3) From this quantity (E1-1), how much did you consume (in Kg)?	|____|.|__|
E1-4) From this quantity (E1-1), how much did you sell (in Kg)?	|____|.|__|
E1-5) From this quantity (E1-1), how much did you give away (in Kg)?	|____|.|__|
E1-6) From this quantity (E1-1), how much is currently remaining in storage (in Kg)?	|____|.|__|
E1-7) Did you use pesticides during the storage period to protect your crop? *(if no, go to E.*	|____|
E1-8) What is the main type of pesticide used?	|____|
E1-9) Where did you get most of the pesticides from?	|____|
E1-10) According to you, how effective are the pesticides used?	|____|

5

Loss assessment through probability sample surveys

5.1 INTRODUCTION AND RATIONALE

Chapter 4 introduced the various types of data collection and measurement methods. It described the techniques for physically measuring losses, as well as subjective measurement approaches based on farmer reporting. To obtain reliable and statistically representative results, these two measurement methods can be used on randomly selected samples of farms, as is typically the case in most agricultural surveys. This chapter provides guidance on how to conduct loss assessments using probability sample surveys as the main data collection vehicle.

In probability sample surveys, a sample of farms or fields is constructed through the random selection of units at different stages (locations, villages, farms, fields, etc.). The data is then collected from the final units. The measurement techniques (physical, declaration-based or other) can be used in isolation or in combination with one another. For example, farmers can be asked to provide their own estimates of grain losses, enumerators can perform field measurements to assess losses during harvest and other on-farm operations, visual scales may be used to assess storage losses, grain samples may be selected and sent to laboratories for analysis, etc.

The rationale for using probability sample surveys is that they ensure statistically representative results for different agro-ecological zones or administrative groupings. In other words, estimates generated by probability sample surveys can be considered as representative of the targeted population (for example, smallholder maize producers at national or regional level). This property is required by users (governments, etc.) that require solid data at national or subnational level to better assess food availability or to monitor post-harvest management programs, for instance.

To ensure statistical representativity, sample sizes must be sufficiently large, which makes sample surveys a relatively costly data collection method. It is therefore recommended to use sample surveys for the country's strategic crops and for the major loss critical points, as identified through preliminary assessments or supply-chain analysis. There are several other ways to reduce data collection costs for PHL assessments. A first possibility is the inclusion of a PHL module in existing sample surveys covering farms or agricultural households that are carried out on a regular basis at national level. In such a setting, the additional cost of collecting information on crop losses would be considerably reduced, as the additional time required to reply to the PHL module would be limited.

This chapter describes how the relevant units can be selected using a random procedure, and presents how and at which levels different measurement methods can be used. This chapter starts by presenting basic statistical concepts of sample surveys as well as elements on sampling procedures for different target populations and survey objectives. The use of data collection methods, such as declarative or physical measurements, within a sample survey context are also presented.

5.2 BASIC CONCEPTS OF PROBABILITY SAMPLE SURVEYS

The implementation of a probability sample requires a proper sampling design (which units to select, how, and in what number), a sampling frame (set of units from which the sample will be selected), as well as adapted estimation techniques based on the data collected. Some of the basic concepts of probability sample surveys are defined below.

Sampling units. These are the units selected through the sampling strategy. The sampling units can be geographical or administrative areas, villages, households, fields, etc., depending on the objectives of the survey and the sampling design adopted. Typically, in agricultural surveys, there are several stages of selection: in a first stage, enumeration areas or villages can be selected as primary sampling units (PSUs); in a second stage, agricultural households or holdings can be selected from the sample of PSUs. These are the secondary sampling units (SSUs). Finally, fields (or granaries) can be selected from the sample of SSUs as tertiary or final sampling units (TSUs). The PSUs and TSUs will vary depending on the stage of the post-harvest process at which the losses are measured. Listings of all these units (sampling frames) are necessary to carry out a random selection of the sampling units.

Sampling frame. This is the set of units (universe) from which a sample is drawn. Several sampling frames are typically used at different stages of sample selection. The nature of the frame depends on the nature of the unit to be selected: if the first unit to select is a predefined geographical area, characterized by geographical coordinates, the frame can be a listing of all latitude and longitude coordinates delimiting the areas (agro-ecological zones, enumeration areas, etc.); if the unit to select is a household, the frame can be a listing of identifiable households, and so on. The frame should be as complete and up-to-date as possible to avoid biases in the results.

For agricultural surveys, a typical sampling frame consists of a list of agricultural holdings in given areas of the country. Other frames used for agricultural surveys can be listings of fields, plots, parcels, storage facilities, etc. depending on the objective of the study. Ideally, the frame should cover all holdings in the country. Business or farm registers established in some countries may constitute an ideal frame, but these are generally limited to commercial or large farms. The construction of frames for agricultural surveys should ideally come from an agricultural census that provides a complete enumeration of agricultural households or holdings. In the absence of agricultural censuses, a population census with an agricultural module can provide a listing of agricultural households that may also serve as a suitable frame. Aerial photographs, satellite imagery and maps can also be used to construct area frames, that is, a set of geographically delimited zones which may constitute sampling units.

Building a suitable sampling frame is normally the very first stage when planning an area-wide loss assessment survey. For assessing on-farm losses, the recommendation is to use the same sampling frame, if not the same sample (or subsample), as for the agricultural surveys. For off-farm losses, frames for the intermediaries will have to be prepared. If there are no off-farm surveys in place, an ad hoc frame must be constructed.

Probability sampling. This method of selecting units is based on a random process that ensures that every unit of the sampling frame has a known probability of selection. Random number tables or random number generators can be used to perform the selection process.

Probability sampling is different from purposive or judgmental sampling, two non-probability sampling methods according to which the researcher chooses the sample based on what they think would be appropriate for the study or for practical reasons such as proximity of the farm or interest of the holder in the study. With a non-probabilistic sampling strategy, it is not possible to attribute a selection probability to each unit and therefore to determine the number of units in the target population that they represent (sample weights), thus precluding the analyst from extrapolating the survey results to the entire target population. Second, selecting units based on non-probabilistic techniques may generate bias in the results. For example, farmers that have a specific interest in PHL may in fact be those that experience lower losses in comparison to other farmers, for instance because they may be implementing mitigation measures and wish to know whether these are effective or not. If the sample overrepresents these farmers, the results will be biased.

Sampling design. It defines how the units of the population are selected from the frame and the number of units to select (sample sizes). In other words, the sampling design defines the probabilities of selection of each sampling unit for each stage of selection. Sampling designs define both the number of selection stages (one or more stages), the stratification (by agro-ecological zone, farm size, etc.) and the sample selection procedure. At each stage, units can be selected based on a simple random selection (each unit in the population has the same probability of being selected) or more sophisticated designs, such as using probabilities of selection proportional to the size of the unit (number of households in a given area, number of fields in a holding, etc.). Typically, agricultural surveys in developing countries are based on several stages of random selection, as described earlier in this section. The targeted sample size is usually a compromise between the available budget and the properties that the analyst or policy-maker requires for the final estimate, particularly in terms of precision and level of statistical representativity. The derivation of an "optimal" sample size can be calculated through a formula relating sample size, the targeted standard deviation and the budget allocated to the study.

5.3 DEFINING THE PURPOSE AND SCOPE OF THE SURVEY

The design of a sample survey starts with the characterization of its objective. For agricultural surveys, the first decision to make often concerns the set of commodities to be covered. The importance of the commodity for farmers' incomes and livelihoods is a key criterion. The foregone revenues for cash crops due to losses occurring in the supply chain may also be a strong reason to include a commodity in the assessment. This choice rests with the institutions involved in the pilot survey (ministry of agriculture, central statistics bureau, agronomic research bureau, etc.) that have a good knowledge of their country's agricultural sector and supply chains, and with the main users and potential beneficiaries of better loss data (public and private decision-makers).

Once the commodities are chosen, different units can be sampled depending on the activity, operations and points of the supply chain targeted for the assessment. For example, if the main interest is to measure on-farm losses, the activities to be covered include the operations of harvesting up to storage. Relevant units are the farm, fields, storage facilities, bags or containers, etc. If the objective of the study is to measure storage losses, the main units will cover the farm (for on-farm storage) as well as off-farm operators and their storage facilities. The choice of activities, operations or points of the supply chain to cover in a sample survey is a function of the objective of the assessment and of the loss critical points identified through supply-chain analyses and loss preliminary assessments (see chapter 4). To facilitate the process of selection and prioritization, it is useful to map and characterize the different activities, channels and units of observation, as in the following table.

TABLE 2. ACTIVITIES, CHANNELS AND UNITS OF OBSERVATION.

Activity/channel	Coverage of the activity	Unit observation
Harvesting	Cutting of standing crop	Plots, fields, parcels
Collection	Stacking, bundling and transportation up to the threshing floor	Stacks, heaps, bundles, etc.
Threshing	Separation of grain from crop manually or using thresher and collection of straw and grain	Bundles, heaps, stacks, etc.
Winnowing/cleaning	Collection of threshed material, winnowing to remove chaff, dust, etc.	Bags, specific containers, etc.
Drying	Collection of material after cleaning, spreading for drying, heaping after drying	Bags, boxes, specific containers, etc.
Packaging	Collection after winnowing/cleaning/drying/sorting/grading/threshing, filling in bags/baskets/other packaging material	Bags, baskets, packaging material
Transportation (on- and off-farm)	Loading of packed material in threshing yard, transportation to store of farmer, unloading for storage, transportation from threshing yard to market yard, unloading at market yard, etc.	Trucks, bags, boxes, etc.
Storage (on-farm)	During storage, cleaning/grading, before sending to market for sale or own consumption	Bags, baskets, boxes, granaries, etc.
Storage (at warehouse/wholesale level)	Unloading, during storage, loading for further sale/disposal	Bags, drums, boxes, etc.
Storage (at retail level)	Unloading and loading, during storage, sorting/grading for sale	Bags, drums, boxes, etc.
Storage (at miller/processor level)	Unloading material for storage during storage	Bags, drums, boxes, etc.

Once the scope of the sample survey has been defined, the sample selection procedure must be determined. This is addressed in the following section.

5.4 SAMPLE SELECTION PROCEDURES

5.4.1 For farm-level units

Standard sampling procedures are described below for the different activities or points of the supply chain. The basic principle is that all units, at any stage of selection, should be selected using a random procedure. Although the procedure to determine the overall sample size (for example, the total number of holdings to survey) is not described in detail here, as is common to sample surveys, indications on relative sample sizes at each selection stage will be provided. For example, the proportion of second-stage units to select in a sample of first-stage units (the number of farms to select in a village or enumeration area).

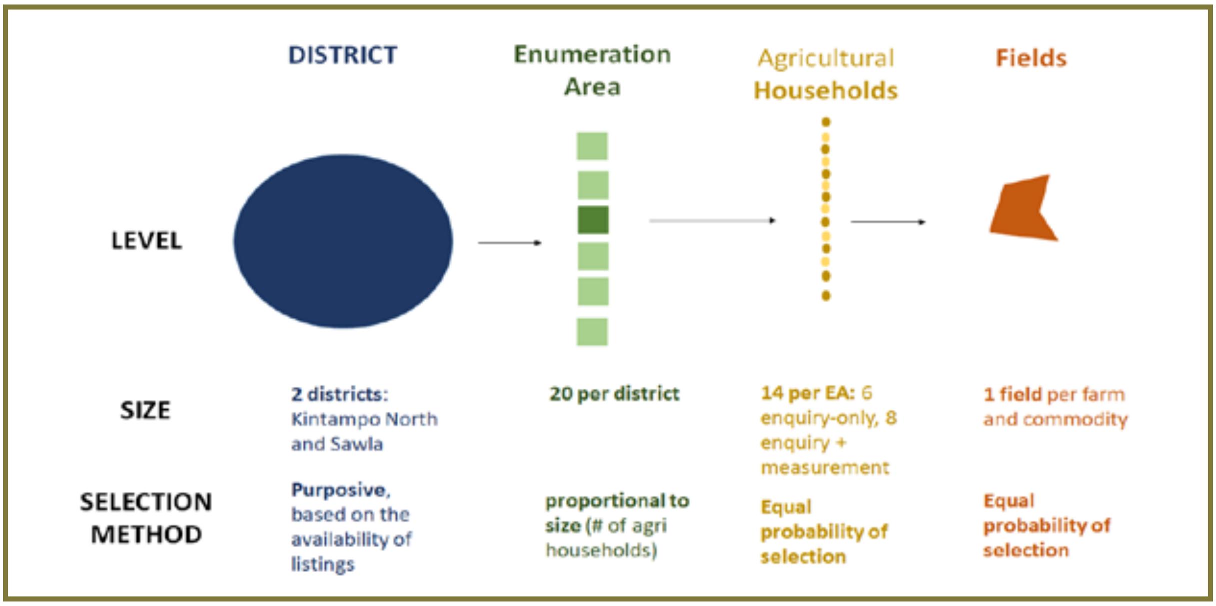
The sampling strategy recommended for loss assessments is in essence very similar to the standard procedures used by countries for their own agricultural or farm surveys, especially if the loss assessment is, as recommended in these Guidelines, attached to an existing farm survey. The general procedure, stratified multi-stage random sampling, is briefly described here with a focus on the specificities in relation to loss assessments.

Stratification. The first step consists in defining an adapted stratification scheme. This is done by selecting the variables that can segment the population into sufficiently homogeneous groups with respect to the variables of interest of the survey. The stratification scheme for loss assessment surveys can be similar to the stratification used for a standard production survey, with variables such as agro-ecological or climatic zones, farm size or farm type (for example, subsistence versus commercial) that are typically used as stratification variables. For example, in a given country, there are areas where maize, sorghum and pearl millet are grown and strive optimally, while in other areas these crops may not benefit from the same growing conditions; this bears an impact on average yields, losses and other variables.

Sampling stages. Once the stratification has been defined, the different units can be selected in each stratum. Depending on the administrative subdivision of the country (region, province, district, etc.), a first sample of units corresponding for example to the country's highest-level administrative division (districts, etc.) is randomly selected. These will be the PSUs. In each PSU, SSUs such as enumeration areas, villages, etc. can be randomly selected at a second stage. In each SSU, a sample of households can be selected as TSUs or final sampling units if this is the last stage of selection. Additional or fewer selection stages may be required depending on the specificities of the country: the selection may end at the village level if variability within villages is perceived as low; on the contrary, additional steps may be required to reach the field level or to select storage units, bags, etc. To obtain more precise estimates (in terms of smaller variances), it is generally recommended to use higher sampling rates for the first selection stages, to cover as many PSUs as possible. Lower sampling rates can be used for the selection of tertiary and subsequent units (households, fields, etc.). This recommendation assumes that variability within higher-level units is greater than for lower-level units: for example, the variability in yields or in PHL between districts can be assumed to be higher than the variability between enumeration areas of a given district or among households of a given enumeration area.

For loss assessments, this sampling procedure can be adjusted if physical measurements are to be undertaken in addition to standard farmer enquiries. As physical measurements are complex, time-consuming and expensive, it is recommended to restrict them to a subsample. A two-phase sampling approach can be used, where a subset of farms is randomly selected from the sample of TSUs. For this subset of farms, physical loss measurements will be undertaken in addition to the standard enquiry. This sampling strategy, which was used in the 2016–2017 Ghana pilot survey (GSARS, 2017a), is illustrated in figure 15.

FIGURE 15. A POSSIBLE SAMPLING STRATEGY FOR A SURVEY ON FARM-LEVEL LOSSES.



Source: GSARS, 2017a.

Sampling procedure

For PSUs: The sampling frame for PSUs is constructed by establishing a list of all eligible PSUs in each stratum. If the PSUs are administrative divisions, these listings are usually readily available. In cases where loss studies are coupled with production surveys (as recommended in this document), the recommended approach is to select the sample of PSUs with a probability of selection proportional to the size of each PSU. This will provide a representative measurement of production. If the objective of the survey is only to estimate percentage losses (a ratio), a simpler selection procedure, for example based on proportional allocation[1], is sufficient. The size of each PSU can be measured by variables such as the number of enumeration areas, census blocks, villages, households, agricultural households, crop area, crop production, etc. Data for the size variable chosen must be available for each PSU of the list and be as up-to-date as possible. Simple random selection, that is, assigning an equal probability of selection to each PSU, can also be used; however, it is not recommended here as, for a given sample size, it leads to less precise estimates.

For SSUs: In each selected PSU, a list of SSUs is prepared. If PSUs are districts, SSUs can typically be census blocks, enumeration areas or villages. The list of SSUs and their measure of size (number of households, etc.) must be as complete and up-to-date as possible. These listings typically come from the last population or agriculture census. As for the PSUs, probabilities of selection proportional to the size of each SSUs can be used. Proportional allocation could also be used if the survey only intends to measure percentage losses and not yield, production or area. Size variables such as the number of agricultural holdings or arable land area are often used in agricultural surveys and can also be used for a PHL survey or module.

For TSUs: In each selected SSU (village, etc.), a list of farming households growing or expected to grow the commodities of interest is prepared. This enumeration exercise is repeated for each survey, as farms may exit or leave the target population, for example if they no longer cultivate the targeted crop. Optionally, this list may be stratified into categories of farming households growing different percentages of the crops.

1 When proportional allocation is used, the number of units within each stratum have the same probability of being selected (the same sampling rate). The number of units to be selected in each stratum is therefore proportional to the relative size of each stratum in the total population. For example, the use of a 10 percent sampling rate in a stratum comprised of 100 units leads to the selection of ten units, whereas five units would be selected in a stratum of 50 units. The relative sample sizes (10/5) is equal to the relative stratum sizes (100/50).

For fields and other lower-level units: Additional units may be selected depending on the objective of the study. For example, for physical measurements, fields must be selected. If resources do not allow for selecting and carrying out measurements for all fields, a sample may be selected using a simple random design, assigning equal probabilities of selection to each field. Prior to the selection, a list of all fields in the sample of TSUs (farms) must be established, stratified by crop.

5.4.2 For off-farm units

Losses outside the farm occur during storage, handling, transportation and processing at different points of the supply chain: collection points in cooperatives, harbours, processors, markets, etc. To measure these losses, an adapted sampling strategy must be devised. The sampling procedures presented below typically apply to developing countries, especially but not exclusively sub-Saharan African countries. In any case, the procedure should reflect the country's specificities.

Wholesale markets. A frame of wholesale markets (SSUs) must first be established. This can be done by preparing or obtaining from the relevant authorities the list of wholesale markets in the PSUs' main or two main cities. If wholesale markets are not available in the selected PSU, nearby PSUs can be considered. From this list, one or two wholesale markets can be selected using a simple random design. In each selected market, all wholesalers are enumerated and stratified by commodity to construct the frame of TSUs. From this frame, a sample of wholesalers for each commodity is selected using equal probabilities of selection (simple random design). In some countries, wholesale markets may be specialized by commodity, some selling exclusively fruits and vegetables, others cereals, meat, etc. In this case, the SSUs can be stratified by commodity group and a small number of markets from each target group selected at random. The selection of TSUs (wholesalers) remains unchanged.

Retail markets. A sampling procedure analogous to that used for wholesale markets can be adopted for retail markets, with certain specificities: (i) retail markets are in general more numerous and more geographically dispersed than wholesale markets – as a result, a higher number of retail markets may need to be selected, covering a wider geographical area than the main one or two cities, as in the case of wholesale markets; and (ii) in some countries, the distinction between wholesale and retail markets is not clear. For example, the market may only accept wholesalers in the morning and be open to retail sales in the afternoon. In this situation, the two types of markets can be considered as a single one, as the characteristics in terms of storage losses are likely to be very similar.

Processors. The overall sampling procedure is the same as for wholesale and retail markets. The only difference is the need to stratify the processing facilities by commodity: rice processing facilities, flour production units, etc. A proper frame of processors must be established to select a sample. Such a frame may be obtained from business registries or other relevant sources.

Large storage units. Examples of such units are facilities where important amounts of grains are kept as strategic reserves. Large amounts of cereals are also stored at strategic export and import points, especially close to harbours. Cooperatives and private trading companies also run large storage facilities where the grain purchased from farmers is stored before dispatching. Some of the specificities of large storage units are that: (i) they are generally present in small numbers, authorizing in some cases a complete enumeration (census) instead of a sample selection; and (ii) they may be located outside the PSUs used to select farms or markets. Listings of these units are usually available from the relevant country authorities and business registers: customs offices for export and import points, ministries of agriculture, farmers' unions or cooperatives, etc. Once the listings are established, it is recommended to categorize the units by commodity and, depending on the size of the target population, either to select all units (in the case of large public grain storage sites, for example) or a sample of them (for private storage facilities, for example) using simple random sampling.

Selection of observational units: refer to section 5.5.2.1.

5.5 DATA COLLECTION AND MEASUREMENT

Once the units have been selected using an appropriate sampling design, data collection and measurement can take place. The different measurement approaches described in chapter 4 – farmer declarations and physical measurements in particular – can be used. The choice essentially depends on the objective of the study, the type of loss to measure (storage or other types, etc.), the point of the chain selected (on- or off-farm) and, naturally, the amount of resources available for the assessment. This section briefly describes the different methods, with an emphasis on operational considerations and on elements that have not been covered in chapter 4.

5.5.1 Enquiry-based data collection

An appropriate set of questionnaires must be prepared to collect information from farmers on losses, their causes and possible prevention measures.

On-farm. Farm-level data on losses can be collected using the following questionnaires:

- Questionnaire for complete enumeration of households in the selected SSUs (villages, etc.): it must include identification details of the village as well as information on the nature of each holding, such as the crops grown or expected to grow during the survey period and areas under crops. The farmers are selected on the basis of this information.
- Questionnaire for data collection on losses during farm activities, including harvesting, collection, threshing, sorting or grading, drying, packaging, and transportation. Farmers are asked to provide their own assessment of the quantitative loss for each of the farm activities. Data concerning the activity, the method used (such as harvesting), the equipment used, and the quantities handled and lost are recorded.
- Questionnaire for data collection on losses during storage at farm level.

Examples of questionnaires are provided in sections 4.5.2 and 4.5.3.

Off-farm. For enquiries with non-farm actors, such as processors or wholesalers, the following set of questionnaires can be prepared:

- Questionnaire for the complete enumeration of the selected market channels. Based on this sample frame, the targeted units of the supply chain will be selected.
- Questionnaire for collection of loss data during storage in market channel.
- Questionnaire for data collection on losses for off-farm activities, including processing, transportation/distribution, marketing.

To estimate losses along a chain, information about quantities retained or handled in each operation and channel during storage is needed, as well as the corresponding percentages. Specific questionnaires must be developed and data collected from a suitable number of respondents, the sample size depending on the resources available and the circumstances in the study area. These respondents should be knowledgeable individuals from agronomic research institutes and similar organizations who are capable of providing the best estimates of the percentages, handled by channel, based on their experience, judgement, previous data and findings from surveys of small groups of market stakeholders. The questionnaire provided below (figure 16) illustrates how data on losses during storage can be enquired upon with off-farm actors.

FIGURE 16. COLLECTING DATA ON OFF-FARM LOSSES THROUGH INQUIRY.

SECTION B: LOSS DURING STORAGE (by inquiry)

B1) Region: .... Code region |___| B2) Constituency: .... Code |___|

B4) Actor Name: .... B5) Actor serial Number |______|

B6) Type of actor |_____| B7) Name of the enumerator: ....

Date of visit	Crops	Type of storage	Main cause of loss	Previous balance (tons)	Additions during inquiry period (tons)	Withdrawal during inquiry period (tons)	Total amount stored (tons)	Quantity lost (Kg)	Main action implemented to prevent losses
B8	B9	B10	B11	B12	B13	B14	B15	B16	B17

Codes for B9: 01= Mahangu/Millet; 02=Maize

Code for B6: 1= Wholesaler; 2= Processor; 3= Government warehouse

Codes for B10: 1= Traditional; 2= Modern

Codes for B11: 1= Mechanical Damage (spillage); 2= Physiological process; 3= Pest infestation

Codes for B17: 01= Re-drying; 02= Storage hygiene; 03= Use of chemicals; 04= Timely application chemicals; 05= Use of protected granaries; 06= Repair granary; 07= Don't know; 08= Nothing; 09= No losses; 10= Other

Timing and frequency. The timing of an enquiry-based assessment is important as it affects the capacity of the farmer to recall the information. To minimize the recall bias, the survey should be fielded as closely as is feasible to the phenomenon that is being measured. For enquiries regarding losses during harvesting and other farm operations prior to storage, the visits should take place at harvesting or within a week or two later. Subsequent visits can be made to record the losses incurred during storage.

For off-farm actors, timing is less critical as traders, processors and other actors of the supply chain tend to keep better track of their activities. It is however recommended to survey these actors during the periods when they handle the largest amounts of commodities.

Some challenges are associated with the definition of a proper schedule and timing of visits. Undertaking several visits to farms and other supply-chain actors increases the cost of survey operations. In addition, if the PHL assessment is attached to an existing farm or business survey, the timing and frequency may have to follow the schedule established for the main survey. The final choice will be a compromise between the first best approach, the budget availability and the operational feasibility.

5.5.2 Collecting data via physical measurements

Physical measurements can be undertaken to measure both the losses incurred during on-farm operations and those arising during off-farm storage, transport, processing, distribution, selling and any other point of the chain.

5.5.2.1 On-farm loss measurements

The standard physical measurement methods are described in section 4.4. This section seeks to provide operational guidance on how to undertake these operations, highlighting the possible challenges, biases and ways to overcome them.

Physical measurements should be undertaken for the critical stages at which on-farm losses are likely to occur (see table 2, section 5.3). These stages vary from crop to crop and according to the unit of interest (farmer, processor, etc.). For farm-level losses for grains, the critical stages are harvesting, threshing or shelling, stacking or stooking, cleaning or winnowing, drying, and storage. Transport, processing, packaging and handling are more relevant for off-farm actors.

Harvesting, threshing, cleaning and other operations prior to storage. Whether carried out mechanically or manually, it is important that these operations be performed using the farmer's usual practices. This means that the enumerator, supervisor or extension officer carrying out the measurements must be perfectly acquainted with the farming practices followed in the locality. To facilitate the process, the teams may ask for the help or guidance of the farmer or farm workers.

For pulses and cereals such as sorghum, millet or wheat, the samples of straw or chaff selected for measurement (grain sorting, counting and weighing) may be smaller than those selected for maize. It is important to record all these measurements on the forms designed for this purpose (see figure 7, section 4.4).

Transportation. Losses during transport at the farm level may occur in (a) moving the harvested produce from the field to the threshing floor; and (b) from threshing floor to the storage. Losses are normally estimated as the weight difference between the quantity loaded and the quantity unloaded. Measurement challenges include difficulties in weighing the produce, especially if it is loaded on trucks or carts as bulk or in important amounts. In such a situation, the team may adopt a different strategy and try to pick up and weigh the amount of produce falling during transportation. As this is a tedious process, survey designers must decide if these losses are significant enough (for example, from prior assessments) to justify the effort and expenses put into data collection.

Processing. There may be some degree of processing of grain done on the farm, especially for rice. If this is a common practice, this stage can be included in the loss assessment and the measurements carried out as recommended for professional mills in section 4.4. However, grain processing is most often done in professional mills of different sizes, and losses at this stage generally belong to the off-farm sector.

Storage. The estimation of storage losses through physical measurements involve periodic visits to the farm's storage facility and the collection of grain samples, and their sending to a laboratory for analysis, as described in section 4.4. In some cases, once enumerators have collected the grain samples, they can also use visual scales to derive percentage losses while in the field. These visual scales are established in advance, before the start of the fieldwork. This requires preliminary fieldwork to collect grain samples and carry out appropriate laboratory analyses to establish the visual scales. Laboratory work, at one point or another of the process, cannot be avoided. However, once the visual scales are established, they do not need to be updated each year.

The enumerator should take advantage of each visit to assess the farm's grain stocks by asking the farmer how much of the targeted commodity is currently stored, how much was consumed since the last visit, how much was sold and how much was added to the stock (from gifts or purchases, for example).

Below, recommendations are provided on how to select observational units and grain samples from the farm store.

Identification and sampling of observational units: The process of selecting grain samples starts with the identification and selection of observational units. The observational unit is the smallest division or unit in which grain is held. It might be stacks in the field, bags, small silos or granaries on a farm, or woven baskets. The accuracy of the estimation of losses at storage depends on the accuracy of the loss measurement for each observational unit. After identification, a sample of observational units must be selected. If several units are present on the farm, such as bags, the recommendation is to randomly select at least two units. The random selection can be carried out using a table of random numbers or a random number generator.

Selection of grain samples from observational units: The main principle is that at least two samples from different parts of the observational unit should be taken. Indeed, not all of the grain in the container has the same biophysical characteristics (moisture content, etc.) and is exposed in the same way to pests and rodents. The smaller the observational unit, such as bags or baskets, the easiest it is to select grain samples from different parts of the container (top, centre, etc.). On the contrary, for larger units such as silos or granaries, the process of selection of grain samples is more complex and the enumerator might be obliged to select grain from one specific side of the container (such as on the top), which may lead to systematic errors in the measurements and derived loss estimates. All samples must be packed appropriately, labelled and identified with information relative to the date of collection, the exact location of the source, the weight of the sample, grain type, variety, time in storage and type of storage. Once collected, the samples should be sent as soon as possible to the laboratory for analysis.

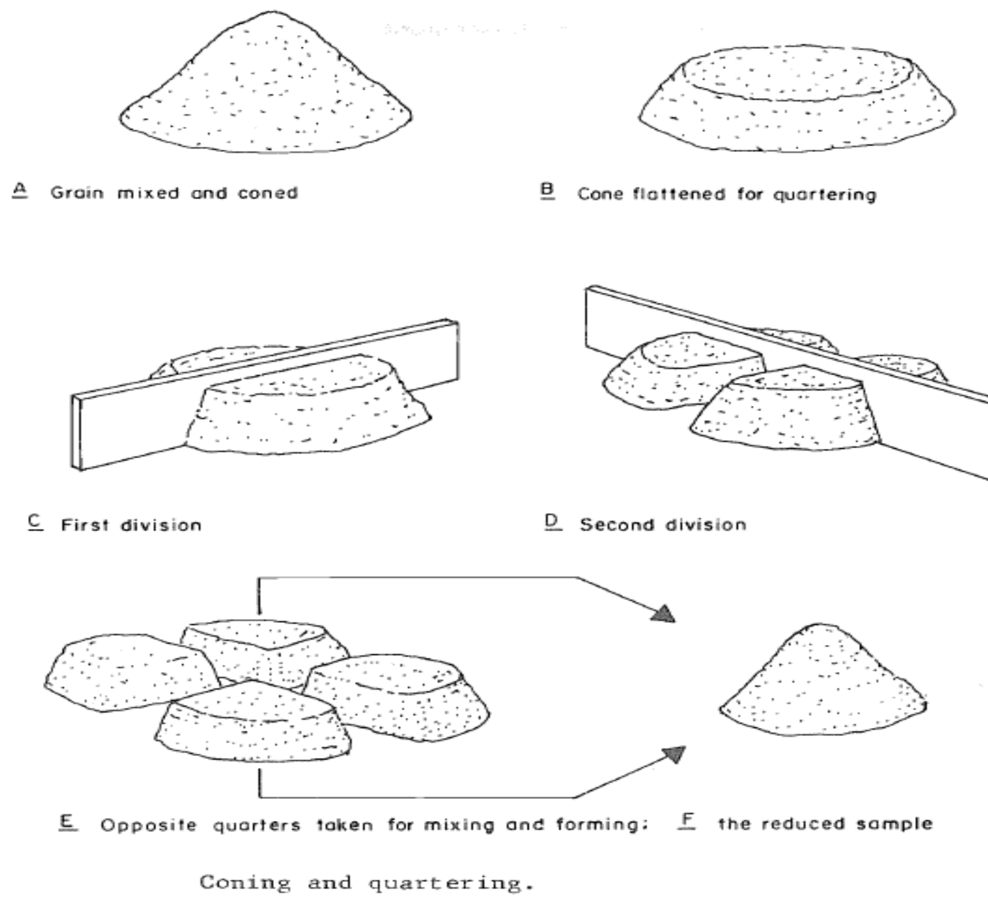
Below, the standard sampling methods found in specialized literature for the most common observational units are provided.

Case 1 – For crops stored unthreshed in stacks located directly in the field:

- Identify and number each stack;
- Select a minimum of two stacks at random;
- Thresh or shell, using the farmer's chosen method, each selected stack;
- Reduce the grain by coning and quartering (see figure 17) to a sample of, say, 1 kg to 1.5 kg (record the weight in the form).
- Package the sample for transmission to the laboratory.

If each stack contains less than 2 kg of shelled grain, the grain from two stacks can be combined into a single sample for transmission to the laboratory.

FIGURE 17. CONING AND QUARTERING.



Source: Boxall, 1986.

Case 2 – For threshed grain stored in baskets: the grain selection process is the same as for the previous case.

Case 3 – Unthreshed grain stored in large cribs, silos or granaries:

- Option 1: Unload and shell the entire lot contained in the cribs, silos, or granaries. Then cone and quarter to obtain a sample of, say, 1 kg to 1.5 kg.
- Option 2: Unload the grain equally into baskets, select randomly at least two baskets and cone and quarter to obtain a sample of, say, 1 kg to 1.5 kg.
- Option 3: Ears of cob maize or panicles of sorghum or millet are labelled randomly as the crib is filled. The farmer may then be asked to set these ears aside as he or she encounters them during emptying. These ears or panicles are then threshed and the grain obtained reduced to a sample of, say, 1 kg to 1.5 kg through coning and quartering. This procedure is operationally complex and requires close coordination and cooperation with the farmer. It may not be suitable to a large-scale survey. This procedure should be used only after its applicability to the local situation has been studied carefully.

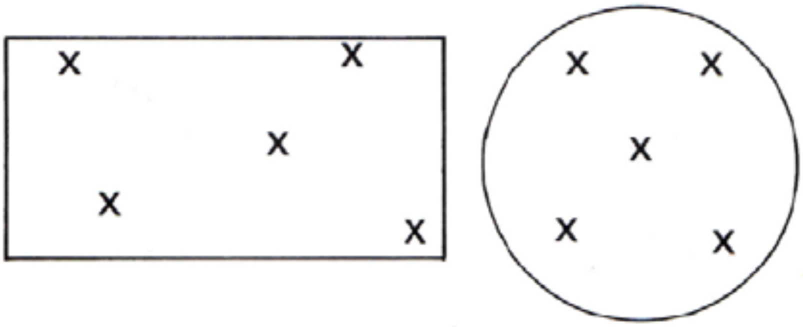
Case 4 – Large bulk storage units of threshed or shelled grain:

Obtaining a representative sample from a large bulk container is difficult. A possible approach is outlined below:

- The grain is transferred into another container in such a way that samples can be selected as the grain falls into the new container. A container small enough to be handled easily should catch the entire falling grain stream until it is full. The grain caught from the stream is placed into a larger sample container. This procedure is repeated at frequent and regular intervals throughout the transfer.
- When all the grain has been transferred, the collected sample may be reduced by coning and quartering to, for example, 1 kg to 1.5 kg for transmission to the laboratory.

If it is not possible to sample the grain during a transfer, then a sampling probe may be used. In using the probe, an effort should be made to reach every part of the storage container. Samples can be taken with the probe in the positions shown in figure 18, preferably using a compartmented probe.

FIGURE 18. PROBING LOCATIONS IN RECTANGULAR AND ROUND BINS.



Source: Boxall, 1986.

Case 5 – Mass storage in bags.

- A sample of at least two bags is selected.
- The whole bag is emptied and a sample of, for example, 1 kg to 1.5 kg is selected by coning and quartering. The same is done with the other bags and the samples are merged into one, which is finally reduced through coning and quartering to a final sample of 1 kg to 1.5 kg.
- The remainder can be returned to the bags and to the store.

A less satisfactory alternative is to obtain a sample from each randomly chosen bag by probing.

The sampling procedures should always be reported, especially when the sampling is suspected to be non-representative as in the case of stacked bags, unshelled grain heads and cobs, and when there are visually observed concentrations of insects or mould, or both.

5.5.2.2 Off-farm measurements

Intermediary level. In this category, reference is made to government distribution agencies, mills, marketing cooperatives, wholesale traders and retail traders. At this level, losses are to be estimated mostly for storage and processing, although other steps (such as packing and handling) can also be added if relevant. Once the different off-farm units are selected (see section 5.4.2 for more details), the required information is collected and the physical measurements are made. The estimation techniques are similar to those used for determining on-farm losses, particularly for the transport and storage phases. These techniques are described in section 5.5.2.1 and section 4.4. The particularity compared to loss measurement at the farm-level is that samples of intermediates will be considerably smaller than samples of farmers. The enumerators can therefore focus their efforts on a smaller number of units and concentrate on carrying out precise and complete measurements. Furthermore, intermediaries, especially large traders and processors, generally maintain good records of their activity and of the key biophysical parameters (temperature, moisture content, etc.) that may affect the condition of the grain that they are storing, processing or handling. This information can serve as a complement to the physical measurements, as well as for cross-validation operations.

Government warehouses. These warehouses are often managed by public distribution agencies and maintain detailed administrative records of the grains received and dispatched. Food technology specialists working in these agencies are expected to collect samples of grains periodically to measure pertinent information, such as moisture content, insect and pest infestation and other causes of damage. These agencies should therefore have readily available, comprehensive data on levels of losses and their causes. To obtain the required data on losses, the recommendation is thus to rely as much as possible on these records and on the expertise of technicians and engineers working in these facilities.

5.6 DATA ANALYSIS METHODS: COMPILING THE KEY INDICATORS

Once the data has been collected using the different approaches presented in this chapter, it undergoes a series of controls, checks and verifications. These are standard operations used in any survey, and will not be detailed in these Guidelines. In addition to data entry and validation procedures, specific checks will need to be designed to ensure that data on losses have been entered properly and are consistent with other variables of the survey: losses at harvest cannot be higher than harvested quantities, etc.

This section focuses on describing the key indicators that can be compiled from a PHL survey and how to properly estimate statistically representative totals, averages and the associated standard deviations.

5.6.1 Key PHL indicators and their characteristics

The PHL survey should be able to generate the data required to compile indicators on losses both in quantity and percentage terms. These indicators are described below.

Quantitative (or weight) losses. These losses, generally expressed in kg, are either collected from the farmer (enquiry approach) or generated by physical (or objective) measurements. Totals can be aggregated at the village, enumeration area, district, region and country level if desired, depending on the objectives of the survey, the administrative division of the country and the stratification and sampling procedure used.

Absolute indicators are useful in the sense that they provide an indication of the amounts lost, which can be directly subtracted from food production to assess a country's food supply situation. These amounts can be used for food security analysis or to estimate import demand and export potential, for example. However, absolute indicators do not provide information on the intensity of losses, such as their importance relative to overall production or the loss intensity for each single operation or step of the chain (harvesting, storage, transport, etc.).

Economic losses. The quantities lost can also be valued at the market-selling price or producer price to measure gross economic loss or loss expressed in value terms. These economic losses are gross and not net because there are costs attached to the reduction of losses, such as the purchase of better machinery, additional and better trained labour, etc. that are not considered. In general, the higher the losses (in quantity or percentage terms), the lower the cost of reducing losses and vice versa.

Relative (or percentage) losses. Percentage or relative indicators measure the intensity of losses for the different harvest and post-harvest operations considered. They are calculated by dividing the estimated quantities lost at each stage by the estimated quantities handled at that stage. For example, percentage drying losses are calculated by dividing the quantities of grain lost during drying by the quantities brought to drying. Using handled quantities (in this case, quantities brought to drying) as the denominator ensures that percentage losses are comprised between 0 percent and 100 percent. This measure of relative losses indicates the relative amount lost at each stage of the process.

Although using quantities handled as the denominator of loss indicators is the recommended approach (see Jha *et al.*, 2015), analysts can also present the loss estimates (for on-farm losses) as a percentage of total harvested quantities. This facilitates comparisons between loss estimates for different operations (threshing, drying, etc.), as well as their conversion to quantities, by multiplying by harvested quantities.

The measurement of percentage harvest losses is a special case. Indeed, by definition, harvested quantities already exclude harvesting losses. Using the former as the denominator could lead to harvesting losses higher than 100 percent (in case of high losses due to a special event, for example), which would not make sense. Relative harvest losses should therefore be measured using the sum of harvested quantities and harvest losses as the denominator. The different indicators are summarized in table 3.

TABLE 3. KEY VARIABLES AND INDICATORS.

Variables	Absolute (kg)	Relative (%)	Comments
Quantities:			**All variables refer to a single unit (agricultural holding, trader, etc.)**
Harvested	H		
Brought to:			
Threshing/shelling	T		
Cleaning/winnowing	C		
Drying	D		
Transportation	T		
Storage	S		
Losses during:			
Harvesting	L_H	$l_H = \frac{L_H}{H + L_H}$	$H + L_H$ is a measure of potential harvested quantities
Threshing/shelling	L_T	$l_T = \frac{L_T}{T}$	
Cleaning/winnowing	L_C	$l_C = \frac{L_C}{C}$	
Drying	L_D	$l_D = \frac{L_D}{D}$	
Transport	L_{Tr}	$l_{Tr} = \frac{L_{Tr}}{Tr}$	
Storage (farmer declarations)	L_S	$l_S = \frac{L_S}{S}$	
Storage (physical measurements)		$l_S^{(t)}$	$t = n$ visits; $l_S^{(t)}$ is the percentage storage loss at visit t calculated using appropriate physical measurements (e.g. count and weigh method).
Aggregates:			
PHL	$L_{PH} = L_T + L_C + L_S$	$l_{PH} = \frac{L_{PH}}{H}$	
Harvest losses and PHL	L_{HPH}	$l_{HPH} = \frac{L_{PH} + L_H}{H + L_H}$	

5.6.2 Estimation of loss indicators based on survey data

Once calculated at individual level (farm, trader, etc.), averages or totals can be compiled for different aggregated units, such as villages, districts, regions and countries, using a calculation methodology that reflects the sample design adopted for the survey. This calculation methodology ensures that the indicators are statistically representative at the desired level (villages, districts, regions, etc.). The calculation procedure is presented below in general terms.

Quantitative (or weight) losses. Total quantity losses for a given area or administrative unit are estimated by the formula:

$$\hat{L}_j = \sum_{i \in S_j} w_i \,.\, L_i$$

Where:

- j is the index representing the lowest administrative level or stratum (enumeration area, census block, etc.) pertaining to the sample;
- i the index representing the individual unit for which the data is collected, such as a farm, a household, a warehouse or a milling facility;
- S_j the sample of individual units randomly selected in j;
- w_i the sample weight of the unit i in the stratum j, and;
- L_i the weight loss of the given commodity measured for unit i. This variable may refer to loss at any stage (harvesting, threshing, transport, etc.) and to any measurement method, enquiry-based, physical measurements, visual-scales or other.

Quantity losses for higher strata are estimated by summing the lower-level estimates, weighted by the respective sample weights. For example, losses for a given district are estimated by:

$$\hat{L}_d = \sum_{j \in S_d} w_j \,.\, \hat{L}_j$$

Where: d is the index representing the district, S_d the sample of lower-level strata (such as enumeration areas) pertaining to district d and w_j the sampling weight of stratum j in d.

Economic losses. If the selling price is collected for the individual unit, economic losses at the lowest level are calculated by:

$$\widehat{eL}_j = \sum_{i \in S_j} w_i \,.\, p_i L_i$$

Where:

- $\widehat{eL}_j$ is the estimate gross economic loss (loss in value terms) for the stratum j;
- p_i is the selling or producer price per unit of commodity declared or calculated for i. The unit of the price must be the same as the unit in which the losses are measured (such as kg).

Selling prices may not be known at the individual level but only at village or district level, for example. In such cases, the estimated economic losses are simply the product of the estimated price and the quantity losses. For example: $\widehat{eL}_j = \hat{p}_j \, \hat{L}_j$, if average prices are known for the first level.

Relative (or percentage) losses. Percentage losses are estimated as a ratio of quantity losses to the quantity handled (or quantity handled plus quantity lost, in the case of harvest losses):

$$\hat{l}_j = \frac{\hat{L}_j}{\hat{Q}_j}$$

Where:

- $\hat{Q}_j$ is the estimated quantity used as the denominator: $\hat{Q}_j = \Sigma_{i \in Sj} w_i . Q_i$, and;
- $\hat{l}_j$ is the estimated percentage loss for stratum j.

For the strata immediately above j, percentage losses are determined in a similar way. For example, for a given district:

$$\hat{l}_d = \frac{\hat{L}_d}{\hat{Q}_d}$$

A convenient calculation procedure, derived from this ratio, is given by:

$$\hat{l}_d = \sum_{j \in S_d} \theta_j(Q) . \hat{l_j}$$

Where:

- Q is the relevant denominator for the type of measured loss. For example: $Q = H + L_H$ for harvest losses, $Q = T$ for threshing losses and so on for the other operations (see table 4 for the full list).
- $\theta_j(Q) = {\hat{Q}_j}/{\hat{Q}_d}$ is the weight of strata j in d

Further details on the estimation procedure can be found in Jha *et al*. (2015), among others.

5.6.3 Estimation of variances, standard deviations and confidence intervals

One of the advantages of probability sample surveys is that they can provide an indication of the precision of the estimated indicators. This precision is generally measured by standard deviations, coefficients of variation and confidence intervals. An operational procedure to calculate variances, standard deviations and confidence intervals for percentage losses is provided below.

Standard deviations. To calculate standard deviations, variances must first be determined. As percentage losses are estimated as a ratio of two estimates, its variance cannot be obtained directly but must be approximated. Using the standard approximation of the variance of the ratio of two random variables, the variance of percentage losses at district or primary sampling level is given by:

$$\hat{V}(\hat{l}) = \left(\frac{\hat{Q}}{\hat{L}}\right)^2 \left[\frac{\hat{V}(\hat{L})}{\hat{L}^2} + \frac{\hat{V}(\hat{Q})}{\hat{Q}^2} - 2\frac{\widehat{COV}(\hat{L},\hat{Q})}{\hat{L}.\hat{Q}}\right]$$

Where:

- $\hat{V}(\hat{L}) = \frac{1}{n(1-n)}\sum_j \left(\hat{L}_j - \frac{\hat{L}}{n}\right)^2$ is the estimated sample variance of weight losses;
- $\hat{V}(\hat{Q}) = \frac{1}{n(1-n)}\sum_j \left(\hat{Q}_j - \frac{\hat{Q}}{n}\right)^2$ is the estimated sample variance of the denominator;
- $\widehat{COV}(\hat{L},\hat{Q}) = \frac{1}{n(1-n)}\sum_j \left(\hat{L}_j - \frac{\hat{L}}{n}\right)\left(Q_j - \frac{\hat{Q}}{n}\right)$ is the estimated sample covariance between weight losses and the denominator;

- n is the number of SSUs (enumeration areas, etc.) selected in each district.

The standard deviation is defined as the square root of the variance: $\widehat{SD}(\hat{l}) = \sqrt{\hat{V}(\hat{l})}$

Confidence intervals. These provide the interval to which the true (unknown) value is likely to pertain. To construct a confidence interval, three elements are necessary: the estimate of the indicator (such as the average percentage losses), its estimated standard deviation and its estimated or assumed probability distribution. It is often assumed that the (standardized) indicator follows a normal distribution. With this assumption, the 95-percent confidence interval for percentage losses is given by the following formula:

$$IC_{95\%}(\hat{l}) = \left[\hat{l} \mp 1.96.\widehat{SD}(\hat{l})\right]$$

This means that the true and unknown percentage losses have a 95-percent chance of pertaining to this interval. The assumption of normality can be relaxed: other distributions may be chosen or the empirical probability distribution determined by non-parametric methods.

5.6.4 Going beyond: improving estimates by pooling enquiry-based data and physical measurements

The estimation of average percentage losses through the pooling of physical measurements and enquiry-based estimates may improve the overall accuracy and precision of the final estimates.

In its simplest version, the pooling procedure is based on a weighted average of each type of estimator. Jha *et al*. (2015) use the standard deviations of the respective estimates as weights. Denoting $\hat{l}_1$ as the declaration-based estimate and $\hat{l}_2$ as the estimate based on physical measurements, the pooled estimate $\hat{l}$ is given by:

$$\hat{l} = \frac{\widehat{sd}_2.\hat{l}_1 + \widehat{sd}_1.\hat{l}_2}{\widehat{sd}_1 + \widehat{sd}_2}$$

The principle guiding this approach is to give a greater weight to the most precise estimate, precision being measured by the standard deviation. For example, if declaration-based estimates are less precise ($\widehat{sd}_1 > \widehat{sd}_2$), they will be given a lower weight ($\frac{\widehat{sd}_2}{\widehat{sd}_1+\widehat{sd}_2}$) in the final estimate, and reciprocally.

More sophisticated estimation approaches combining the information generated by these two types of estimates can be implemented. Examples include using ratio or regression estimation to improve the loss estimates. For instance, improved estimation can be obtained from the regression of observed losses on declared losses and a range of farm characteristics. The estimated parameters could also be used to provide quick loss projections. Additional details on this type of modelling framework are given in chapter 7.

5.7 SUMMARY OF THE RECOMMENDATIONS

The different steps that the statistician should follow to conceive and implement a PHL survey are set out below:

Purpose of the assessment. The purpose of the survey should be clearly stated, shared and accepted by data producers and users. For example, the main purpose may be to identify effective loss prevention and reduction measures, to provide quick initial estimates of losses for several commodities, to determine robust and representative estimates for major food crops (such as maize), to determine global estimates needed for the monitoring of SDG indicator 12.3 on food losses, etc. The main and secondary objectives of the survey need to be clearly laid out because to a large extent, they will shape the data collection and measurement strategy.

Review of existing assessments and prioritization. Before engaging in any work on additional surveys, it is important to carry out an assessment of the existing studies on loss estimation, such as value-chain analysis or rapid loss appraisals. The results may be used to identify major gaps, in terms of crops, sectors and methods used, and to better target the critical loss points. This preliminary work will reduce the risk of duplication and contribute to an effective use of resources by ensuring that the focus is placed on the relevant loss points and dimensions. In the absence of solid prior evidence on food losses, it is recommended to carry out a pilot survey or quick assessment before the main loss survey, to identify the most serious grain loss points in the country's post-harvest food supply system.

The main PHL survey should be conducted in priority for those specific loss points of relevance to the country. Further, given the complexity of physical measurements and their consumption of human and financial resources, these Guidelines recommend measuring PHL for the most important crops from a food security, production or income perspective.

Integration of loss assessments in existing statistical activities. Designing and optimizing PHL assessments should be undertaken within the country's information system. The existing statistical activities should be leveraged as much as possible to ensure an efficient use of limited resources and to facilitate the integration of information between different surveys and data sources. A medium- to long-term integrated programme of data collection activities encompassing primary and secondary data sources, including PHL studies, should be collaboratively designed, implemented and regularly monitored by the main key stakeholders, among which the ministries in charge of agriculture, national statistical offices, agronomic research institutions, universities, etc.

As an illustration, if a program of agricultural surveys already exists in the country in question, in the form of annual area and production surveys for example, an additional module could be easily added to measure PHL. The cost of this additional module would be limited, given that it would be attached to an existing survey; however, this could be sufficient to capture key information on losses at regular intervals and for a sufficiently large sample of farms. The same argument is valid for off-farm assessments that could be attached to existing business surveys or specific surveys covering actors of the food chain (wholesale markets, etc.)

Choice of data collection and measurement approach. Once the decision to undertake a PHL survey has been made, the sample selection strategy must be specified and the measurement approach clearly defined. In the context of developing countries, these Guidelines recommend using multistage random sampling, with probabilities of selection proportional to size, to choose the districts, enumeration areas and other geographical segments; and simple random selection to select final units, such as farms or fields. This sampling approach is consistent with the integration of loss assessments in existing yield or area surveys. For stand-alone loss surveys, as the objective is to estimate a ratio, simpler selection procedures based, for example, on proportional allocation can be used. In terms of measurement methods, given that none are exempt from bias and uncertainty, these Guidelines recommend combining estimates from declarations and physical measurements using statistical pooling techniques.

Survey period, length and frequency. As in any survey, the PHL survey must be fielded as closely as possible to the phenomenon that is being measured, especially if the data collection relies on farmer recall. For example, if the measurement of harvest losses and immediate PHL is targeted, the survey should be conducted soon after harvesting.

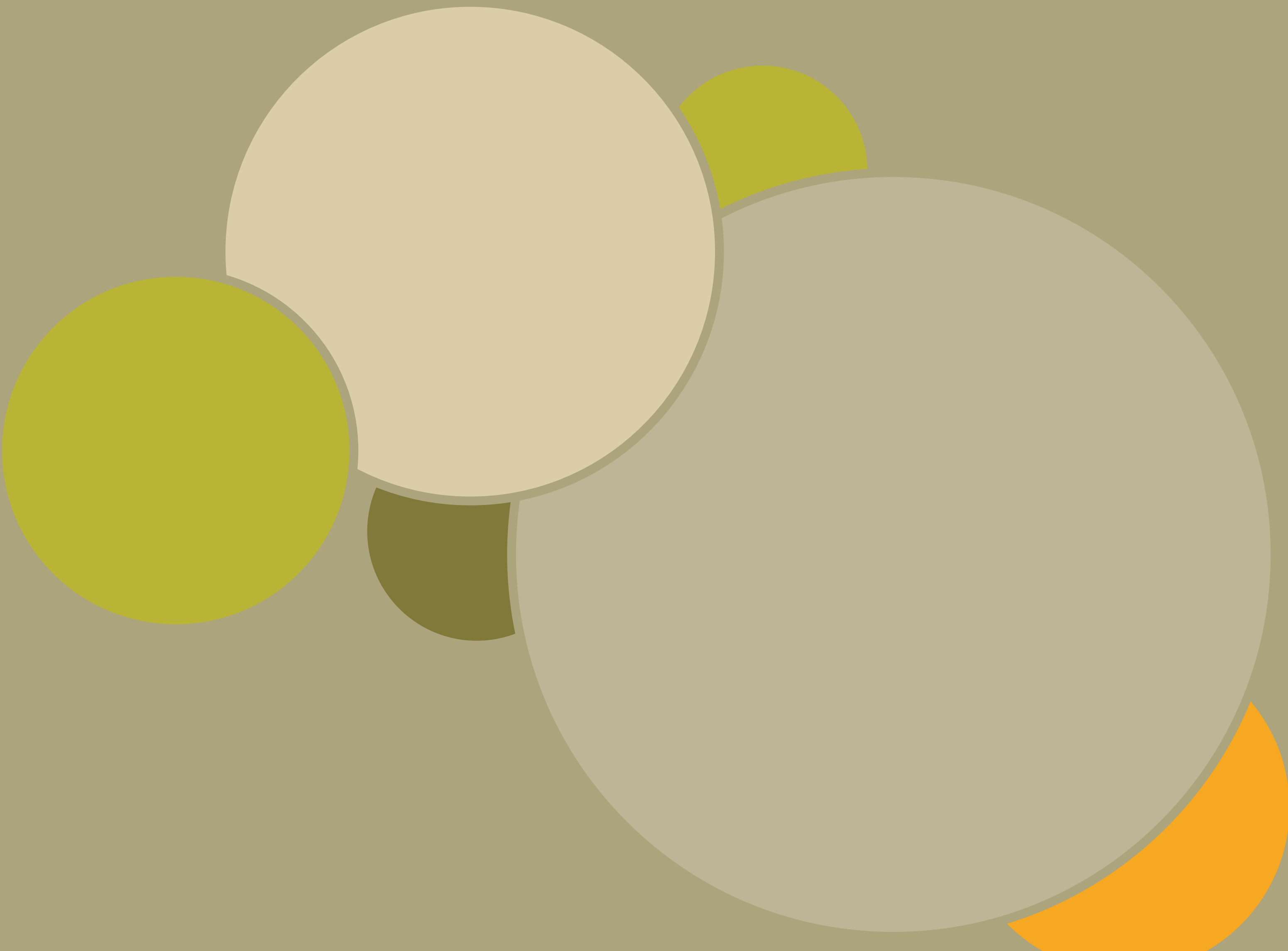
These Guidelines also recommend collecting PHL data for one full cycle of the retained crops, from harvesting to storage. The length of this period depends on the country and the crops. For grains, a period of study covering six months after harvest is considered as a minimum to assess losses arising during storage on the farm. Off-farm assessments should also be properly timed to coincide with the periods in which actors are handling the largest amounts of produce.

Regarding frequency, it is not recommended to carry out a complete loss survey every year, as loss ratios by activities tend to be stable from one year to the next in normal production conditions. A frequency of once every three to four years, with lighter surveys in between based on farmer declarations, may be a recommended approach. However, in the absence of any prior solid evidence on losses, these Guidelines recommend carrying out two or three consecutive comprehensive PHL surveys to establish a first solid set of estimates. Indeed, estimates limited to a single year have a higher risk of being biased because of the occurrence of specific events (a particularly wet year, for example), as compared to estimates based on two- or three-year averages.

Data compilation and analysis. The loss indicators for each stage can be calculated in absolute terms (for example, in kg) or in relative terms (for example, in terms of percentages). In line with most studies on this topic, these Guidelines recommend presenting the indicators in percentage terms. This facilitates comparisons and ensures more robust results. Indeed, relative indicators tend to be more stable than absolute indicators and less affected by measurement biases. Additionally, if harvested quantities are measured well, relative estimates can easily be converted to quantities through a simple multiplication.

When compiling the relative estimates, the denominator must be chosen in accordance with the objective of the assessment. These Guidelines recommend using handled quantities at each stage (threshing, cleaning, etc.) as the denominator of the relative estimates. Indicators can also be presented using harvested quantities as the denominator, to facilitate comparisons of loss intensity between different stages and processes. For the specific case of percentage harvest losses, the denominator should be the sum of the harvested quantities and the losses occurring during harvesting.

If a probability sample survey is used, as recommended for the main loss assessment, it is important that the indicators be compiled according to the sampling design used, as explained in section 5.6.2. In addition, analysts are strongly recommended to accompany the average indicators with their respective standard deviations and confidence intervals (section 5.6.3).



6

Loss assessment through field trials

6.1 INTRODUCTION

Field trials are commonly used to measure crop losses for different varieties and under different growing conditions. They allow relative depth in the assessment of the influence of certain factors on losses, such as type of equipment, post-harvest management techniques, and production practices. Field trials are controlled experiments designed in such a way that the effects of key explanatory factors on losses can be isolated. They are often used to assess the differential impact on yields and losses of the introduction of new crop varieties (for example, GMO or improved) or production practices and equipment.

Field trials cannot capture the entire diversity of agricultural production systems, because they tend to be based on small samples of fields. These estimates cannot be interpreted as representative at regional or national scales. However, they can provide a good indication of the magnitude of losses. They are also useful when investigating specific causes of losses arising under specific conditions in more depth. Field trials should be part of the array of methods used in identifying the loss critical points, from which the scope (commodities, chain, etc.) of the main loss assessment can be determined.

This chapter presents the most common designs used in field trials aiming to measure crop losses. A recent study conducted in Ghana to estimate rice losses on the farm will be presented as an illustration of this approach. This chapter focuses on field trials, which constitute a type of controlled experiment adapted for farm-level assessments. Other types of experimental trials are used to assess losses at other stages of the supply chain. For example, a specific controlled experiment is required to assess losses during off-farm milling operations. While the physical measurements and protocols differ across experiments, the overall approach and types of designs remain the same.

6.2 METHODOLOGY

The concepts defined here are common to most field trials conducted in agriculture, and are not specific to loss assessments. The fundamental structure and methodology are based on the following four components:

- The characterization of the fields or plots (experimental units);
- The definition of the treatments to be applied on the experimental units;
- The identification of the rules and procedures used to assign treatments to experimental units; and
- The determination of the physical measurements made on the experimental units.

6.2.1 Characterization of experimental units: fields and plots

An experimental unit is the smallest unit in a controlled experiment that may receive different treatments. When designing an experiment, researchers pay attention to the size of the experimental unit as well as to its representativeness.

For experimental designs adapted to the measurement of harvest losses, the experimental units are therefore fields or plots. Other experimental units are required for making assessments at other points of the chain. For example, if the objective is to measure losses during milling, the experimental unit will be the milling machine itself. However, the overall approach in terms of selection of the unit, treatments and analyses is the same. The difference resides in the type of measurements undertaken and the operations covered (for example, crop-cutting, milling).

This approach is illustrated by the experimental design adopted in Appiah *et al*. (2011). The first step is the selection of the fields in which the experiment will take place. In many countries, for practical reasons, trials are undertaken in fields belonging to local agricultural research stations. It is not clear if this is the case in the study described in Appiah *et al*. (2011), as this only indicates that the experiment took place in two localities of the Ejisu-Juabeng District, Ashanti Region. In each of the selected fields, subplots of 4 m x 5 m were placed and used for the experiments. One of the objectives of the study of Appiah *et al*. (2011) was to compare PHL for two different varieties of paddy, Nerica 1 and Nerica 2. Within each field, two subplots were therefore demarcated, one for each variety.

The number of plots to be considered depends on the design of the experiment. The main components of standard experimental design for field trials are presented below, starting with the treatments.

6.2.2 Treatments

In field trials, a treatment refers to the type of operations and practices that are performed on the plots and that are assumed to influence the variable of interest. The objective is to estimate the impact of each treatment on the variable of interest, relative to a reference or control treatment. The control treatment is necessary in some, but not all, experiments. It is required when the overall effectiveness of the treatment under study is not known, or when the overall effectiveness of the treatment is known but is not consistent under all conditions.

For the measurement of PHL, many production practices may be used as treatments: crop variety, harvesting time and method, threshing method, storage type, crop protection measures during storage, etc. Appiah *et al*. (2011) consider two harvesting methods (panicle versus sickle harvesting), combined with two paddy varieties, as treatments for the estimation of losses at harvest.

To ensure that the effects of each treatment on the variable of interest can be distinguished from other factors, a proper stratification of experimental units is required. For example, fields with similar topographic and biophysical characteristics should be chosen. Additionally, the assignation of the treatments to each field under study should be random, and the procedure replicated several times. An example of a standard experimental design used in agricultural trials is described below.

6.2.3 Randomized Complete Block Design (RCBD)

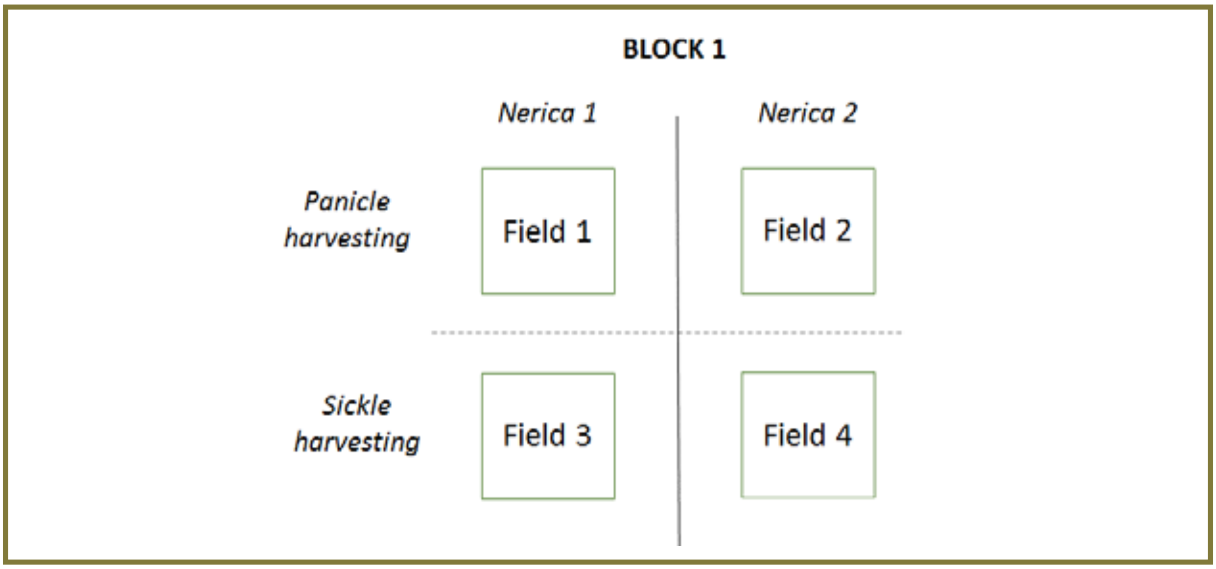
A Randomized Complete Block Design (RCBD) is a type of experimental design that is widely used in agricultural trials, in which each treatment is included in each stratum or block of experimental units, and the treatments are randomly assigned to ensure the statistical validity of the measurements of the effects.

In this type of design, the experimental units are first sorted into homogeneous groups, such as strata or blocks. The main aims pursued when putting experimental units into blocks is to achieve homogeneity within blocks with respect to the dependent variable being studied, and to make the blocks as heterogeneous as possible with respect to the same dependent variable. Examples of blocks are groups of fields with similar biochemical and drainage conditions, and exposure to sunlight.

Treatments are then assigned at random to the experimental units within each block, ensuring that every experimental unit has an equal chance of receiving any one of the treatment. In other words, all possible combinations of experimental units assigned to the various treatments are equally likely. Finally, if analysts wish to test interaction effects between blocks and treatments, the RCBD can be replicated two or more times[1].

Figure 19 below illustrates the design used by Appiah *et al*. (2011): it is a two- (rice variety) by-two (harvesting method) RCBD with three blocks or replicates (only one replicate is shown in the figure). Within each block, the assignment of the fields to each treatment is made at random. Each field within each block has the same probability of being assigned one treatment or the other.

FIGURE 19. ILLUSTRATION OF THE EXPERIMENTAL DESIGN USED BY APPIAH *et al.* (2011).



1 This design is referred to as Generalized Randomized Block Design (GRBD).

6.2.4 Physical measurements

Once the experimental design has been appropriately defined, the physical measurements need to be specified in accordance with the objective pursued. What to measure and how to measure are questions decided by the investigator at the planning stage of the experiment. The measurement should be as unbiased and as precise as possible, as measurement bias leads to difficulties in the analysis of the results and to unreliable and unusable statistics.

The type of physical measurements that may be done within the context of field trials are very similar to those already described extensively in section 4.4. This section will only illustrate the approach adopted in the protocol used by Appiah *et al*. (2011) to measure and explain harvest losses: each plot in each block was harvested using the two methods (panicle and sickle). Leftover grains, both on unharvested standing plants and remaining on the ground, were collected, cleaned, dried and weighted. Harvesting losses in percentage terms were calculated as the ratio of leftover paddy to total harvested paddy.

Two limitations can be identified in this methodology: the grains fallen on the ground prior to the harvest have been counted as harvest losses, whereas they should be considered in theory as pre-harvest losses; using total harvested paddy, instead of harvested paddy plus leftover, as the denominator means that the indicator is not bounded by 1 percent or 100 percent, which is not conceptually satisfactory. The other operations (threshing and milling) were performed for the grain harvested from fields of each block and replicates. For details on these measurements, reader are referred to Appiah *et al*. (2011).

6.2.5 Statistical analysis

The objective pursued in a field trial is to estimate and test the statistical significance of the effects of the treatments (explanatory variables or independent variables) on the variable of interest (dependent variables) and, eventually, to test the effects of interactions between blocks and treatments.

In an RCBD, the statistical framework for estimating treatment and block effects is given by the following model, referred to as the analysis of variance (ANOVA) equation:

$$Y_{i,j,k} = \mu + \alpha_j + \beta_k + \varepsilon_{i,j,k}$$

With:

- $Y_{i,j,k}$ being the calculated harvest losses (assuming this is the variable of interest) for field i, block k and treatment j;
- α_j as the effect of treatment j (for example, harvest method);
- β_k the effect of block k (for example, paddy variety);
- μ as a constant that can be interpreted as the minimum amount of losses at harvest, irrespective of the treatment and stratum or block;
- $\varepsilon_{i,j,k}$ a random error term.

If the number of replicates is sufficiently large, the interaction between blocks and treatments can be estimated using the extended model:

$$Y_{i,j,k} = \mu + \alpha_j + \beta_k + (\alpha\beta)_{j,k} + \varepsilon_{i,j,k}$$

Where $(\alpha\beta)_{j,k}$ is the effect on the variable of interest of the interaction between treatment j and block k.

Once the model is established, the objective of the statistical analysis is to test if the effects on the variable of interest of the different explanatory factors and, eventually, their interactions, are statistically significant. This is done through an ANOVA, according to the general procedure described in annex 5 to these Guidelines.

The sample sizes (that is, the number of fields) will need to be large enough to detect differences in means with a sufficient degree of confidence; at the same time, they should not be so large as to limit study costs.

The statistical analysis performed in Appiah *et al*. (2011) goes beyond what has been presented so far, as such analysis uses a test procedure based on the least significant difference (LSD). This method is usually used to perform pairwise comparisons of the means when the model has three or more factors and when the Fisher test has already led analysts to conclude that the treatments do have an effect on the variable of interest. If the model has only two factors, a standard F-test is sufficient, as only one pairwise comparison is needed.

The decision rule for the comparison of the means is the following: if the difference in the average of the variable of interest between two treatments is higher than the LSD, the hypothesis of equality of means (no effect) between the two treatments can be rejected. Table 4 summarizes the results on harvest losses found in Appiah *et al*. (2011). The LSD statistics indicate that harvesting losses when fields are harvested using sickles are significantly higher than when a panicle is used ($2.93 - 1.39 > 1.34$). On the contrary, using the same decision rule, the rice variety does not have a significant effect on percentage losses.

TABLE 4. HARVEST LOSSES AND TREATMENT EFFECTS.

Treatment variety	Harvesting losses (g)	Harvest weight loss (%)
Nerica 1	132.0	2.19
Nerica 2	148.0	2.13
Panicle	83.0	1.39
Sickle	196.0	2.93
Lsd	59.7	1.34
Nerica 1 x Panicle	66.0	1.13
Nerica 1 x Sickle	197.0	3.25
Nerica 2 x Panicle	100.0	1.64
Nerica 2 x Sickle	195.0	2.62
Lsd	84.4	1.89
CV (%)	11.4	32.3

Source: Appiah *et al.*, 2011.

6.3 PHL FIELD TRIALS IN PRACTICE

The assessment of losses through field trials requires at least three components: (i) an experimental site, which is a specific place within an agricultural research station, generally managed or connected to the country's ministry of agriculture; (ii) an experimental procedure; and (iii) a statistical analysis procedure.

When using this technique in practice, a small-scale farm household survey is often combined with the field experiment. The farm household survey attempts to capture farmers' perceptions and knowledge of PHL issues. The survey generally uses semi-structured questionnaires administered to a relatively small sample of farmers (depending on the resources available), located within the operating radius of the research station. The field experiment could entail different varieties of the same crop grown by the farmers. Each of the varieties is planted on an area of manageable size and replicated several times. Next, agronomic practices including ploughing and weeding are carried out. Finally, at maturity, the crops are harvested, threshed, dried, stored and milled to determine the PHL occurring at each stage.

The type of experimental design is chosen to ensure that treatment effects can be adequately isolated, for example using RCBD. The statistical analysis should be consistent with the design chosen. It will typically be based on an analysis of variance to measure and identify the treatment effects, with or without interactions between the treatments.

It is clear from the presentation that field trials are more of an analytical tool than an approach designed to generate robust and statistically representative PHL estimates. They are useful in assessing the impact of certain farming practices or conditions on losses, but because they generally require complex field operations, measurements and controls, they cannot be based on large samples and therefore lack the statistical robustness and representativity needed to compute region or nation-wide estimates. In any case, they should be an integral part of any PHL assessment framework, both in preliminary stages aimed at identifying loss critical points as well as during follow-up to the main assessment operation, to further explore the explanatory factors behind losses and identify the most effective loss prevention measures.

7

Improving loss assessments through regression modelling

7.1 INTRODUCTION

A wide array of econometric models can be used to improve the estimation of PHL at various stages of the supply chain (farm, wholesale-market and retail levels). All models presuppose that basic information is already available on losses and their main determinants. The data for the modelling may come from different sources, such as standard sample surveys, field trials and aggregated data from administrative sources.

Using modelling to estimate PHL allows researchers to assess the determinants of PHL at various levels of the supply chain and identify the most effective prevention measures. Models are more often used to analyse and explain a phenomenon rather than to measure it, the latter being an activity generally based on standard survey data collection. Data producers are less inclined to use models because their implementation may be complex or require skills that may not be easily found in statistical organizations, and because the structure of the model may not be widely understood. Moreover, the interpretation of model-generated data may be delicate because models need to be re-estimated regularly (the explanatory factors and their weights may therefore change), and because they rely on several hypotheses which may be difficult to verify in practice.

For practical reasons, these Guidelines recommend the use of statistical pooling (see section 5.6.4) as a first approach to improve the quality of PHL estimates. The more sophisticated econometric models such as those presented in this chapter may be used in a second step, and as a priority in countries and statistical organizations with extensive theoretical and applied knowledge of econometrics.

Despite the limitations indicated above, econometric models can be useful in improving the quality of the indicators and their cost-efficiency. For example, if the parameters of the model are well estimated, the data collection can be done on a smaller sample and the model can be used to extrapolate the estimates to the full sample. To our knowledge, the use of econometric modelling to estimate PHL at country level is very rare. The authors of these Guidelines did not identify any application of this approach on a large scale. The approaches presented in this chapter are therefore mostly theoretical and the examples provided refer more to explanatory models than to models with a measurement objective.

7.2 CONCEPTUAL FRAMEWORK

A model is a simplified representation of the relationship between a phenomenon (variable of interest, dependent variable) to measure or explain and its explanatory factors (independent variables). The model assumes a certain functional form, linking the phenomenon to its explanatory factors. For example, PHL may be explained by a set of factors such as farm practices, field size and farm location, linked by a certain functional form (linear, etc.).

Even though models aim to represent reality as closely as possible, notably by ensuring that they contain the main explanatory variables of the phenomena under study, they are nevertheless simplifications, because not all the explanatory variables can be included and because the estimation of the parameters requires a set of simplifying assumptions on the structure of the model (for example, linearity) and the empirical properties of some of its variables. This simplification means that not all variation in the variable of interest can be explained by the model: a portion of it, that should be as small as possible, remains unexplained. This residue, also referred to as the error term, disturbance or noise, is captured in the modelling framework (see below).

Of the wide array of econometric approaches available, this chapter focuses on the multiple linear model, extensively used for a variety of applications. The quantitative dependent variable (for example, percentage PHL) is a linear function of a set of qualitative or quantitative independent variables (farming practices, farm size, etc.) and an error term:

$$Y_i = c + \beta_1 X_{i,1} + \cdots + \beta_K X_{i,K} + \varepsilon_i$$

Where:

- Y_i is the dependent variable measured for $i = 1, \ldots, n$ units (fields, farms, etc.);
- $(X_{i,1}, \ldots, X_{i,k}, \ldots, X_{i,K})$ the set of K explanatory variables measured for i;
- $(\beta_1, \ldots, \beta_k, \ldots, \beta_K)$ the associated parameters that measure the effect of each independent variable on the dependent variable;
- c is a constant; and
- ε_i an error term, assumed to be random and independently distributed.

- The values of Y_i and $X_{i,k}$ for all i and k can be collected from farm or household surveys, aggregated time-series, panel data or other relevant data sources. In the case of loss assessments, Y could be the quantity lost as declared by the farmer or observed using physical measurements (expressed in relative or absolute terms). As independent variables for loss assessments, one may choose, for example, the type of seed used, the area planted, the agricultural practices for harvesting (mechanical or traditional), etc. In the case of storage, the dependent variable could be the type of pesticide used, the storage facilities, etc.
- The parameters c and β_k are unknown and must be estimated. This estimation can be performed using the Ordinary Least Squares (OLS) principle, by minimizing the sum of the squared residuals ε_i of the model. This well-known regression technique will not be described here (for further details, see Neter *et al.*, 1985). The estimated model can now be expressed according to the following equation, where the variables with "hats" denote the estimated variables and parameters:

$$\hat{Y}_i = \hat{c} + \hat{\beta}_1 X_{i,1} + \cdots + \hat{\beta}_K X_{i,K}$$

This model can be used for projections, forecasting and policy-making.

An important aspect must be noted: this model uses field- or farm-level data, partly or entirely drawn from a sample survey. While the literature on the subject is not conclusive, the use of Weighted Least Squares (WLS) may be more efficient than OLS when working from sample survey data. In the present case, WLS is done by weighting each observation i $(Y_i, X_{i,1},\ldots,X_{i,K})$ by its respective sample weight. In practice, WLS is carried out by running an OLS on the transformed model in which each observation is multiplied by its respective sample weight $(\theta_i\, Y_i,\ldots)$. Intuitively, the fact that sample weights vary across units means that each unit has a different informational content, likely to translate into different variances and justifying the use of WLS.

Solon, Haider and Wooldridge (2013) described the different conditions under which the use of WLS is more efficient than OLS when working from survey data, among which: when the objective of the model is to provide representative estimates, as is this case; and when the sample selection rule is partly correlated with the objective of the survey (for example, measuring percentage losses), a risk known to arise when using non-random selection techniques (based for example on willingness to participate) or when variables used in the sample selection process, such as land size, are correlated with the variable of interest. For security, Solon, Haider and Wooldridge (2013) recommend disseminating both OLS and WLS estimates.

7.3 ESTIMATING PHL USING A REGRESSION MODEL: APPROACH AND EXAMPLES

A possible econometric approach towards improving the quality and cost-efficiency of PHL estimates could envisage the following steps:

Collecting the basic data. The model needs data on PHL (the dependent variable) and on a set of independent variables. As the modelling involves a certain degree of simplification, it is recommended that the data collection be as complete, precise and detailed as possible, including the key explanatory factors. As such, the random sample survey is the recommended data collection approach. Ideally, the main loss assessment should comprise both farmer-declared losses and loss estimates based on physical measurements, as these could also be used in a modelling framework.

Establishing the model. This involves selecting the dependent and independent variables, as well as choosing the functional relationship. A very simplified example could be the following:

$$\mathrm{PHL}_i = \mathrm{c} + \beta_1 \mathrm{Seed}_i + \beta_2 \mathrm{Educ}_i + +\beta_3 \mathrm{Meca}_i + \varepsilon_i$$

With PHL_i being the percentage *PHL* for farm *i* as declared by the farmer, $Seed_i$ the seed type (improved or recycled) used by farm *i* for the commodity under consideration, $Educ_i$ the education level of the holder and $Meca_i$ a variable indicating whether the farm uses mainly manual or mechanical procedures for harvest and post-harvest operations. Another, more realistic, example is taken from Ahmed *et al*. (2013), which estimated the *PHL* relating to kinnow (a citrus fruit). The approach and results from this study are described in box 5. Ahmed *et al*. (2013) use the following functional relationship to estimate losses at the retail level (other models were used to estimate farm and wholesale-market-level losses):

$$\mathrm{PHL}_i = \mathrm{c} + \beta_1 \mathrm{Exp}_i + \beta_2 \mathrm{Unsold}_i + \beta_3 \mathrm{RetailType}_i + \varepsilon_i$$

Where PHL_i is the loss of kinnow in kg for retailer *i*, Exp_i is the experience of the retailer in years, $Unsold_i$ is the unsold quantity at the end of the day, and $RetailType_i$ the type of retailer (shopkeeper or hawker). All quantitative variables are taken in natural logarithms to ensure the homoscedasticity (same variance) of the residuals.

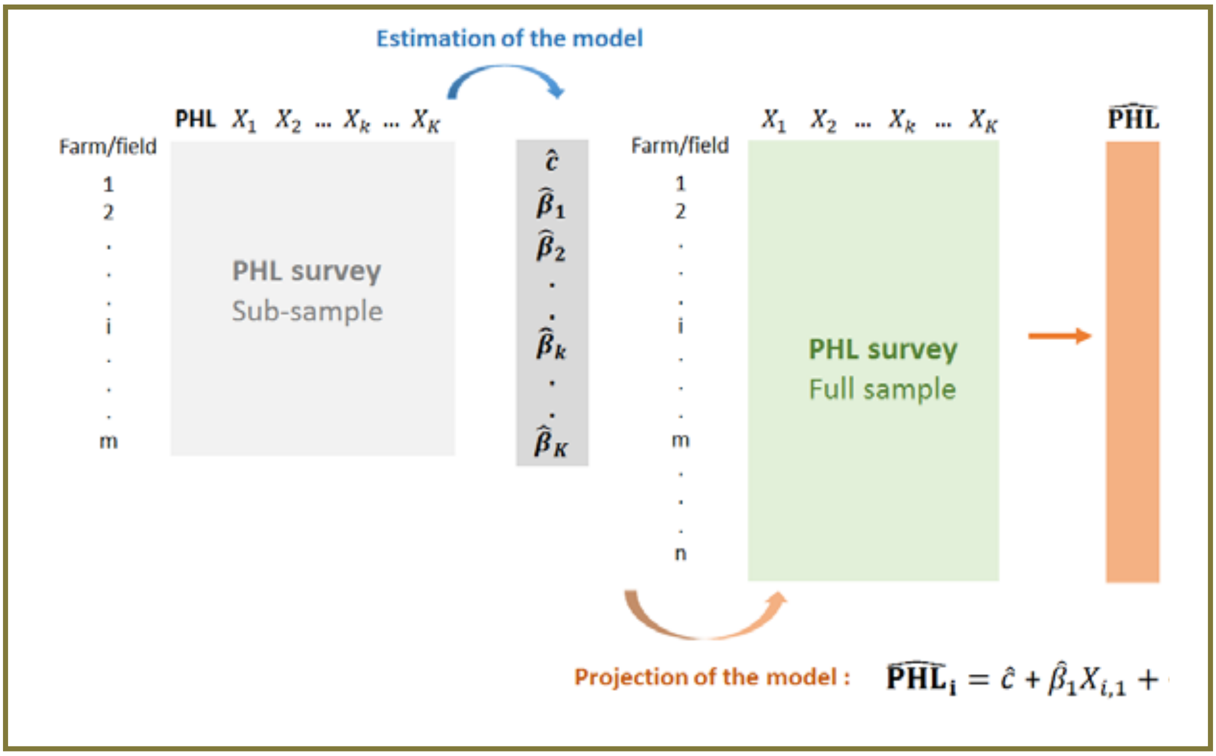
For more precise results, it is recommended to define a model for each major stage of the supply chain, such as farm-level, transformation, off-farm storage and distribution, as losses at each of these stages may respond to specific explanatory factors.

Estimating the model. The model can be estimated using standard OLS or WLS, as presented above and done for example by Ahmed *et al*. (2013). Other techniques, such as maximum likelihood estimation, can be used when functional forms are more complex and to limit the number of simplifying assumptions.

Projecting and forecasting. Once the parameters have been estimated, the variable of interest can be forecasted or projected using the values observed (collected) for the independent variables. If modelling is performed only for explanatory purposes, for example to identify the main explanatory factors of loss and quantify them, the projection and forecasting step is usually not undertaken. The analysis stops with the estimation of the parameters, the interpretation of their sign and tests of their statistical significance.

The projection of losses using estimated parameters and observed values for independent variables is key in improving the quality of the estimations and their cost-efficiency. Indeed, it is not necessary to collect or measure loss for all units of the sample, but rather only for a subsample, for which the regression equation will be estimated. For the other units, data can be collected only for the independent variables and loss projected using the estimated parameters. This process is illustrated in figure 20 below.

FIGURE 20. ILLUSTRATION OF THE MODEL ESTIMATION AND PROJECTION PROCEDURE.



As seen previously in this document (sections 4.4 and 4.5), losses can be determined using physical measurements and farmer declarations. The latter are easier, quicker and cheaper to obtain but are known to underestimate true losses. The former may be biased, notably upwards, as shown in certain studies. This constitutes the rationale for pooling together these two types of estimates, using procedures such as that described in section 5.6.4. While statistical pooling is the approach recommended in these Guidelines, the combination of these two types of measurements to improve the estimation of losses can also be done with regression analysis – sometimes more efficiently and accurately. A possible approach is outlined below.

Assuming that physical measurements, if done properly, constitute a better approximation of true losses, the following estimation procedure could be undertaken:

- **Step 1**: For the full sample of farms, collect data on farmer-declared losses and a range of explanatory or control variables;
- **Step 2**: For a subsample of farms, carry out physical measurements of losses;
- **Step 3**: Estimate a regression model using physical measurements as the variable of interest (left-hand side of the regression equation) and declared losses, as well as any relevant control variables (farm size, seed type, etc.), as explanatory variables (right hand side of the equation);
- **Step 4**: Project the model to estimate losses by physical measurements using the coefficients of the equation estimated in step 3.

BOX 5. A PRACTICAL EXAMPLE: AN ECONOMETRIC ESTIMATION OF THE PHL OF KINNOW IN PAKISTAN.

This practical example summarizes the methodology and findings presented in Ahmed, Liu and Khalid (2013). The objective of this study was to identify and quantify the explanatory factors of the PHL of kinnow, a citrus fruit, for different levels of the supply chain: farm, wholesale market and retail levels. The objective was therefore essentially analytical and explanatory, and not to improve the cost-efficiency of PHL estimates through projections.

Data collection. One district in Pakistan was selected purposively based on its share in the production of kinnow. Within the district, two administrative sub-units (tehsils) were also selected purposively. Then, twenty respondents from each tehsil at each level were selected randomly and according to their size of orchard. Data on quantitative losses was collected from respondents through personal interviews (questionnaires). The authors indicated that a significant share of the respondents was reluctant to reveal correct information.

Modelling framework. To estimate the impact of major determinants of citrus PHL, separate econometric models were used for each stage of the supply chain (farm, wholesale-market and retail levels). Linear "double-log" or "log-log" models were used, in which the logarithmic transformations of the dependent variable and of the quantitative independent variables are used. This is to ensure the fulfillment of desirable properties for the estimation, especially the homoscedasticity of the residuals. The model at farm level is:

$$\text{Ln } L1 = \beta 0 + \beta 1 \text{ Ln } X1 + \beta 2 \text{ Ln } X2 + \beta 3 \text{ Ln } X3 + \beta 4 \, D1 + \beta 5 \, D2 + \varepsilon$$

Where:

- L1 represents the PHL of kinnow in kg
- X1 education in years, X2 experience in years and X3 the Orchard size (in acres)
- D1 is a dummy variable for picking time (1 if picking time is morning, 0 if picking method is evening), D2 a dummy variables for picking method (1 if picked with scissors, 0 if picked manually), and
- ε a disturbance term, with standard assumptions

Estimation results. The results show that all variables have an inverse relationship with losses, except orchard size. These results are in line with expectations. For example, additional experience leads to lower PHL (it is estimated that for every year of additional experience, there would be a 22 percent reduction in PHL, keeping other factors constant). Picking fruits in the morning, when temperatures are lower, also contribute to reducing PHL (see table below).

RESULTS OF THE MULTIPLE REGRESSION ANALYSIS AT FARM LEVEL

Variables	Coefficients	Std Error	t-value	Sig.	Overall fitness
(Constant)	3.839	0.590	6.507	0.000	R2 = 0.406, adjusted R2 = 0.315, F-value = 4.5 at 5% degree of freedom
Ln X1 (education in years)	-0.211	0.138	-1.526	0.137	
Ln X2 (experience in years)	-0.222	0.108	-2.057	0.048	
Ln X3 (orchard size in acres)	0.214	0.074	2.878	0.007	
D1 (dummy for picking time)	-0.276	0.143	-1.936	0.061	
D2 (dummy for picking method)	-0.477	0.218	-2.187	0.036	

Source: Ahmed *et al.*, 2013.

Similar models have been estimated for the wholesale-market level and the retail market level, with specific explanatory factors. For the wholesale market model, for example, variables indicating the quality of road infrastructure were used, as well as loading method and storage place. For the retail market model, unsold quantities at the end of each day was used, among other explanatory variables (see Ahmed *et al.*, 2013, for details).

8

A review of existing loss assessment approaches

8.1 INTRODUCTION

A certain number of loss assessment approaches have been or are currently being used in developing countries. Most of these approaches do not intend to compete with the statistical validity of survey-based methods, whether or not combined with modelling techniques, as described in previous chapters of these Guidelines. These approaches are however worth mentioning, because they can provide loss estimates relatively quickly and for a relatively low cost. They are therefore well adapted to preliminary loss assessments that seek to identify critical loss points and commodities, prior to the conception and implementation of an in-depth assessment preferably based on statistical surveys and estimation techniques.

Three main approaches have been identified and will be quickly reviewed in this chapter:

- The 4S Method, developed by FAO
- The Rapid Loss Appraisal Tool (RLAT), developed by the GIZ
- The African Postharvest Losses Information System (APHLIS)

8.2 THE FAO 4S METHOD

This rapid loss assessment methodology integrates four methods or tools developed by FAO from 2011 to 2016. The methodology is fully described in FAO (2016). This methodology is best adapted to case studies of selected food supply chains. Its objectives are to: (i) identify and quantify the main causes of food losses; (ii) analyse the impact and the feasibility of loss reduction measures; and (iii) identify concrete proposals to formulate a loss reduction program. From these objectives, it is clear that this approach goes beyond measurement itself. The methodology has been field-tested in several countries, such as Cameroon, Kenya and Uganda. This approach is based on four activities or tools, to be used in combination:

(I) Screening: the aim of this activity is to carry out a preliminary screening of food losses, based solely on secondary data and expert consultations.

(II) Survey: a survey on food losses is carried out using questionnaires that are differentiated for producers, processors or handlers/sellers. The approach combines personal interviews of key informant and group interviews. No physical measurements are planned at this stage; however, it is recommended to take photos to back or validate the collected data. The methodology states that the statistical representativity of respondents needs to be ensured, but does not provide any guidance on how to select respondents (for example, randomly or not) or on how large the samples should be.

(III) Sampling: this activity is called "load tracking and sampling assessment" in the methodological document. It aims to carry out physical measurements to assess quantitative losses. The sampling strategy for observational units (bags, grain samples, etc.) is described and involves random selections at several stages. It is also recommended to carry out an analysis of the perceived quality of the product by subjectively assigning a quality grade to the produce from an established food quality scale.

(IV) Synthesis: this activity is called "solution finding" in the methodological document and corresponds to the policy component of the 4S method. An evaluator identifies the cause of losses and proposes solutions to reduce them, which will feed into the development of a wider intervention program on food losses. This activity is done in consultation with the key stakeholders identified in the previous phases.

The 4S method is comprehensive in the sense that it addresses the causes of losses and the associated prevention and mitigation measures. From a technical point of view, the 4S method provides an interesting combination of qualitative and quantitative methods, formal surveys and focus groups or random and purposive selection. The most interesting results are the identification of the points where most losses occur (critical loss points), which can be used in further assessments. It is unclear however how this approach could be applied at a wider scale, for example to estimate losses at regional or country scales. Furthermore, while the measurement itself is described, the methodology does not recommend any approach to aggregate or average percentage losses to reach meaningful results by commodity and chain actor. Finally, the approach does not provide guidance on the selection of the different samples and their respective size. The accuracy or precision of estimates coming from this or similar approaches are therefore difficult to assess.

These Guidelines recommend using this approach for preliminary loss assessments only, in particular to identify the critical loss points that can then be targeted by in-depth assessments. The 4S method can also be used as an alternative method to estimate losses for commodities or points of the supply chain that have been identified as not critical.

8.3 THE RAPID LOSS APPRAISAL TOOL (RLAT)

The Rapid Loss Appraisal Tool (RLAT) for agribusiness value chains was developed by the Sector Project Sustainable Agriculture (NAREN), implemented by GIZ.

The RLAT is a pre-screening tool aiming to provide measures of pre- and post-harvest losses along the value chain, identify key causes of losses and propose measures to mitigate them. In essence, the methodology of the RLAT is similar to the FAO 4S approach, but is much more articulated. The RLAT is a tool that supports "assessment of needs for more in-depth studies that can back public and private investment decisions aimed at reducing losses at the various value chain stages". It is not intended to replace or compete with more ambitious sample survey approaches that seek to provide statistically representative data on losses.

The RLAT was tested in Ghana in 2014. The approach comprises six major steps (See GIZ, 2015a and 2015b):

- **Step 1**: Desktop Study – on the political, socio-economic and agribusiness conditions
- **Step 2**: Key Expert Workshop, including: (i) analysis of hotspots (critical loss points) along the value chain; and (ii) validation of desktop study results
- **Step 3**: Stakeholder Workshop
    - Analysis of hotspots (critical loss points) along the value chain
    - Validation of key expert workshop results
- **Step 4**: Focus Group Meetings
    - Appraisal of the workshop results through a confrontation with observations on the ground
    - Verification of loss perceptions of value-chain operators
- **Step 5**: Key Informant Interviews
    - Validation and completion of results of preceding process steps
- **Step 6**: Assessment and Presentation of Results
    - Plausibility check of results at the different process steps
    - Presentation of aggregated results

The approach encompasses group discussions and individual interviews to assess pre- and post-harvest losses and their causes, and identify the main prevention and loss reduction measures. The toolbox comprises a complete set of questionnaires, procedures and calculation methods that are more comprehensive and detailed than the 4S approach. Furthermore, although this approach does not aim at full statistical representativity, it provides clear guidance on how units (villages, farmers, etc.) should be selected in order to limit potential biases and obtain meaningful results.

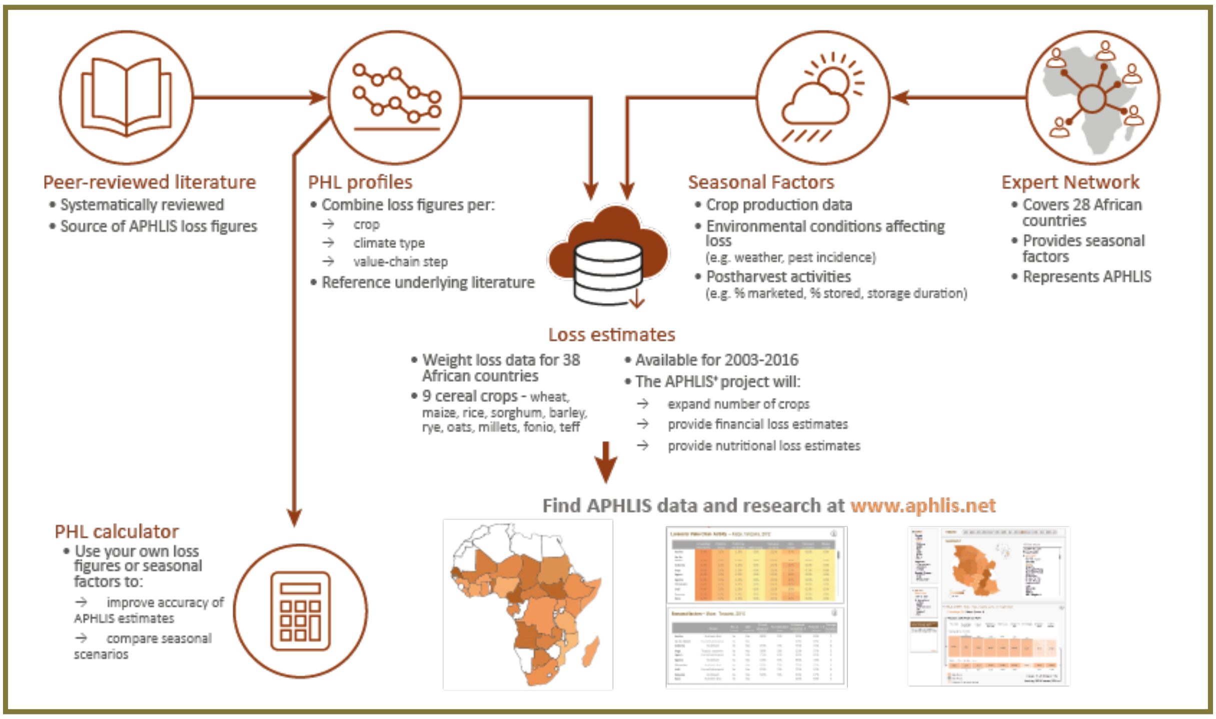
These Guidelines recommend using this approach as part of the preliminary assessments that need to be carried out in preparation of more in-depth studies. This type of assessment approach can also be used to complement standard survey-based methods, for example to better understand the socio-economic dynamics underpinning farming practices and their effects on losses, and to collectively identify the most efficient and adapted prevention and mitigation measures. Finally, the RLAT could also be used as part of the monitoring and evaluation of policies and interventions in the field of food losses.

8.4 THE AFRICAN POSTHARVEST LOSSES INFORMATION SYSTEM (APHLIS)

APHLIS consists of a network of local postharvest experts supported by a database and loss calculator that provide cumulative cereal weight loss estimates from production for sub-Saharan Africa by province, country and region[1]. APHLIS is supported by the European Commission and the Bill & Melinda Gates Foundation.

The estimation methodology used by APHLIS combines the use of secondary data (gathered through its large network of experts) with modelling to generate estimates that intend to reflect the local context and farming practices. Secondary data is used to derive percentage loss estimates at each point of the supply chain (PHL profiles) and combine them with seasonal factors on crop production, climatic conditions, farming practices and market characteristics (among other factors) to generate absolute loss estimates. The process is illustrated in figure 21.

FIGURE 21. APHLIS LOSS ESTIMATION PROCESS.



Source: APHLIS website (http://www.aphlis.net).

The different types of input data in APHLIS are:

- **Crop production**. These data are submitted to the APHLIS central database by the network members, and are derived from primary or secondary data sources mostly from their respective ministries of agriculture. Crop production data is used to evaluate the magnitude of quantitative losses.
- **Percentage of grain lost at each link in the post-harvest chain** (harvesting, drying, etc. up to market storage). These estimates come mostly from the relevant scientific literature and are grouped by crop, climate zone and value-chain step. These parameters, which are regularly updated, constitute the PHL profiles used to construct the cumulative weight loss estimates from production for a province (primary administrative unit) or any user-defined geographical area.

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1 See http://www.aphlis.net.

- Factors varying seasonally or annually, having a significant impact on the percentage losses at key links in the post-harvest chain. These factors are used to adjust the PHL profiles so that estimates reflect local and seasonal conditions. Examples of seasonal parameters include the following:
    - Rain/damp cloudy weather at harvest time that may hinder grain drying;
    - The proportion of the crop that is marketed in the first three months after harvest time, that is, that will not remain in farm storage long enough for significant storage losses to occur;
    - Farm storage duration;
    - The incidence of a pest, such as the larger grain borer that attacks mature maize.

The process of construction of the aggregated percentage loss figures is illustrated in figure 20, which shows the different estimates found in the literature for percentage losses during harvesting and field drying. Here, for instance, the percentage weight loss of 6.4 percent for the harvesting/field-drying link for smallholder maize in the Central Province of Malawi is the arithmetic average of the ten loss figures (specific or not to Malawi, and for different time periods) found in the literature.

FIGURE 20. APHLIS LOSS PARAMETERS AND SOURCES.

Stages	Loss figure	Reference
Harvesting/Field-drying	5.5	Egyir, I.S. – 2011
	2.0	Boxall, R.A. – 1998
	5.0	Vervroegen, D. – 1990
	3.2	Singano, C. – 2008
	6.5	Singano C. – 2008
	6.9	Singano, C. – 2008
	9.9	Singano, C. – 2008
	9.9	Grolleaud, M. – 1997
	5.8	Mvumi, B.M. – 1995
	9.5	Odogola, W.R. – 1991
	6.4	na
Platform drying	3.5	Jonsson, L.O. – 1987
	4.5	Odogola, W.R. – 1991
	4.0	na

Source: APHLIS website (http://www.aphlis.net).

One of the advantages of the APHLIS system is that it seeks to make the best use of the existing information on losses, exploiting secondary data from the existing literature to establish percentage losses and combining them with key parameters that can be adjusted by users to generate loss estimates reflecting local country conditions and seasonal factors (climate, etc.). The quality of the PHL estimates resulting from these calculations is as good as the information from these two sources.

That said, the calculation framework, as any model, is a simplification of the reality. For example, there are several relevant independent variables not covered by the APHLIS system that also influence losses, such as agronomic practices, farm technologies, socio-economic characteristics of holders, etc. In addition, there is the need to clarify the definition of crop production that is used as a basis for the calculations. For instance, it is important to state whether the production of maize from a given country is potential production (derived from an estimate of potential yield) or actual production. This clarification is necessary because using potential production or actual production leads to significantly different estimates of cumulative weight losses (as these are determined by multiplying average percentage losses by the measure of production).

This type of tool or information system is complementary to survey-based approaches, based on declarative estimates or physical measurements. Indeed, if up-to-date and representative survey estimates are available for a given country and commodity, they can be included in APHLIS and replace the multiple sources from which PHL profiles are established. They might still require adjustments, using the seasonal factors defined in APHLIS, if for example survey-based estimates are not available on a regular basis each year.

9

Proposal of an integrated approach to measure PHL

9.1 INTRODUCTION AND RATIONALE

The collection of agricultural data is often a complex and costly undertaking. Measuring PHL is especially complex because of the multiple sources of losses, the many nodes of the supply chain where they can appear, the different types of loss that may be experienced (quantitative, qualitative, economic, etc.) and the difficulty to capture them using either declarative or physical measurement techniques.

These Guidelines, in line with their focus on cost-efficient approaches, emphasize the importance of prioritizing the needs, the identification of the critical loss points and the proper use and integration of the multiple data sources directly and indirectly connected to PHL. Building a measurement approach on the basis of existing country information systems for food and agriculture offers several possibilities to improve the quality of PHL data and information.

This chapter describes the benefits of integrated statistical systems, identifies the different data sources that may be used for the appraisal and measurement of PHL and provides additional guidance on the use of recurring surveys, such as annual production surveys, as a vehicle for collecting data on PHL.

9.2 INTEGRATED STATISTICAL SYSTEMS: CONCEPTS AND BENEFITS

The application of a systems approach for agricultural statistics, as defined by FAO (2009), is useful to systematically determine the resources required to attain acceptable levels of PHL for national agricultural systems. The United Nations Educational, Scientific and Cultural Organization (UNESCO) has several decades of experience in building education information systems around the world. The same observations also apply to the World Health Organization (WHO), which has helped many countries around the world to build their own health information systems. All of these systems make use of an integrated set of data sources that include area-wide sample surveys or censuses conducted by countries within the framework of their national statistical systems. FAO also encourages countries to build food and agriculture statistics within the framework of their national statistical systems.

Several initiatives and publications have described and advocated integrated statistical and survey approaches for agricultural statistics. Among these initiatives, the World Programme for the Census of Agriculture 2010 and 2020 strongly advocate that agricultural statistical systems be articulated around an agricultural census (exhaustive) conducted every ten years and thematic sample-based surveys at predefined frequencies (every two years, every three years, etc.). This modular approach is designed to help countries produce sufficient high-quality data to satisfy their needs at the lowest overall cost. In such a system, a PHL survey may constitute a specific module carried out two or three times in the intercensal period, based on a sample of farms drawn from the sampling frame generated by the agricultural census.

Acknowledging the high cost of censuses and surveys, the Global Strategy has also undertaken research on how statistical units from different surveys or censuses can be linked, allowing a more efficient use of different surveys. The objective of this research is to provide guidelines to countries on how different data sources, especially surveys, can be leveraged to produce agricultural statistics. These Guidelines cover situations where integration is ensured from the design phase (ex ante integration, the preferable approach) but also cases where formal integration was not ensured from the conception stage but must be forced ex post. The outcome of this research was published in the Guidelines on the Integrated Survey Framework (GSARS, 2015). A frequent situation in developing countries is the absence of proper sampling frames for agricultural statistics, which forces countries to use alternatives such as population censuses (based on households) as a frame for agricultural surveys (based on farm holdings). GSARS (2015) help countries to address these issues in the most cost-efficient way.

The objective of integrated agricultural and rural statistics systems is to achieve a well-articulated and integrated data collection framework for the medium to long term, driven by user needs and designed to ensure cost-effective data collection. The benefits that may be expected from a better linkage of different data sources include:

- Conceptual and classification uniformity;
- Optimization of the use of scarce statistical resources;
- Prevention of overloading statistical operations with too many items;
- Ensuring consistency in statistical information (preventing conflicting statistics);
- Facilitation of processing, analysis and compilation of statistical indicators; and
- Facilitation of user availability of collected data and statistics.

9.3 RELEVANT DATA SOURCES FOR CROP LOSS STATISTICS

Every developing country has an agricultural statistical system to start with, potentially with several data sources that may be used to carry out loss assessments. Primary sources of data will be provided through the conduct of surveys making use of sampling techniques. Secondary data from government agencies or research institutions, such as climate parameters (rainfall, temperature, humidity, etc.) or physical characteristics of soils, can be used, because these factors are known to influence crop losses. Agronomic research data generated by field trials and other types of controlled experiments can also be used to estimate losses and identify its causes. This information often comes from government-managed research stations, agricultural research institutions and universities. These data sources are listed and described below. The list does not reflect the data availability in most countries (developed and developing), which would typically be lower.

Annual agricultural production surveys are often conducted every year to provide crop production estimates. This is the most common agricultural survey and can be found in most countries. In some cases, crop forecasting may be part of the survey's objectives. The statistical unit for the agricultural production survey is the agricultural holding and the universe from which the sample is drawn should, if possible, cover all holdings in the country. This assumes that proper censuses have been performed.

Population censuses should be conducted in principle at least once every ten years. This is the most common census and recent data can be found in most countries. This source does not directly provide PHL data, but can be useful in indirectly providing a sample frame and population figures to be used by PHL surveys or studies.

Agricultural censuses should also, in principle, be conducted once over a ten-year period. They can provide data on (a) the structure of agriculture (number of farms, their sizes, farm machinery and equipment) and (b) a frame for other agricultural surveys. The statistical unit is the agricultural holding. Questions can be added to the census schedule concerning the equipment and machinery being used for post-harvest operations. Agricultural censuses are conducted less regularly than population censuses in most developing countries, which means that proper and up-to-date frames of holdings are generally absent.

Farm management surveys can be conducted periodically (for example, twice in a ten-year period) to collect detailed data on key aspects of holding decision-making such as on assets, organizational structure, allocation of resources, input-output relations and production costs. The agricultural holding is the statistical unit. Data on drivers of PHL can be gathered in these surveys, for example on farming practices.

PHL surveys are often conducted on an ad hoc basis, with no fixed periodicity. If available, this survey should be the main data source for loss assessments. Its main objective is typically to measure losses arising because of waste and spoilage of agricultural products at different points of the supply chain, particularly for food grains, the major part of agricultural production destined for human consumption. Since the survey covers losses occurring at various stages of marketing, transportation and storage, the statistical units for the corresponding phases of the survey are agricultural holdings, intermediaries and warehouses, respectively.

Food consumption and nutrition surveys can be conducted periodically (for example, twice in a ten-year period) to collect data on nutrition, such as individual food intake, calorie intake and nutritive value. The statistical unit is the household or the individual, depending on surveys and countries. This type of survey can also be used to collect data on food loss and waste at the household level.

Household income or expenditure surveys (HIES; Living Standards Measurement Survey – LSMS; and Household Budget Survey – HBS) are typically conducted twice in a ten-year period with the aim of obtaining data on the income of rural and urban households derived from all sources and on the expenditure patterns of those households. In this case, the statistical unit is the household. This type of survey can also be used to collected data on food loss and waste at the household level.

Livestock censuses or surveys collect data on both animals and holdings with livestock with a sufficiently broad scope to include all animal husbandry systems, including nomadic ones. The agricultural holding is the statistical unit for this survey.

Other specific surveys, for example those related to the collection of food prices (prices received by farmers, wholesale prices, retail prices, export prices, import prices, and prices paid by farmers). Price statistics may be compiled from specialized price surveys (at any level of the chain, depending on the type of price targeted) or from other agricultural surveys (such as production surveys, to collect farm-gate prices). Food price information is relevant when deriving economic loss due to food wastage and spillage along the chain.

Administrative records may serve some general purposes of PHL studies if they are made available in statistical form. For example, records of prices of imports and exports or data from livestock slaughterhouses are useful sources of data for PHL assessments.

International statistical publications and databases are useful for cross-country PHL comparative studies. A country lacking statistics of its own on a particular topic (such as the PHL of maize) may adapt the statistics of other countries with similar characteristics and conditions with respect to that topic (structure of the farming sector, crop specialization, etc.). These international statistics ensure that the similar concepts, definitions and classification schemes used for data reporting are in line with international recommendations. Examples of useful data on agricultural statistics and food losses, in particular at international level, are provided by FAOSTAT, FAO's data dissemination platform.

Agricultural research information in food and agriculture is generated from laboratories, universities and research institutes. They involve experiments with food crops, agronomic practices, harvesting techniques, storage technologies, animals, and agricultural inputs. The main aim is to measure causal relationships between various indicators (such as harvesting practice and harvest losses), in contrast to other data sources that collect data for measurement and descriptive purposes. This type of research and other data sources complement each other: for example, statistics obtained from censuses and surveys may help in formulating hypotheses to be tested by field trials or other controlled experiments. Research results, on the other hand, may suggest the need for additional information to be collected by censuses or surveys.

9.4 A PROPOSAL OF INTEGRATED MEASUREMENT FRAMEWORK FOR PHL

These Guidelines have presented different approaches to collect data on PHL, each with different objectives, scope, advantages and limitations. While considering that full-scale sample surveys should be used for the main loss assessment, these Guidelines also acknowledge the need to prioritize data collection efforts and to use existing data sources, as well as lighter and less costly approaches, to provide a comprehensive picture of food losses. This section takes stock of these discussions to present a possible assessment framework for food losses that ensures data quality and completeness at an acceptable cost. Figure 23 illustrates the approach proposed.

Preliminary assessment. This activity involves compiling data on losses and its explanatory factors from different data sources, including survey data, value-chain analysis, rapid loss appraisals, field trials and other secondary sources of information. The objective of this preliminary assessment is twofold: (i) make an inventory of the data sources on PHL that may be used in the PHL statistics system; and (ii) provide elements to circumscribe the scope of the main loss assessment in terms of regional coverage, choice of commodity, node of the supply chain and frequency of the assessment.

In this first phase of the loss assessment, semi-structured interviews can be used during community group discussions, focus groups or key informant interviews. This type of interviews or discussions provide a good understanding of the practices and conditions affecting PHL that may otherwise be difficult to capture in standard structured questionnaires. This is the case, for example, of socio-economic factors underpinning farming practices and post-harvest management.

The type of information that can be collected during semi-structured interviews can include:

- The characterization of PHL (causes and prevention measures) within the community;
- Preliminary identification of the critical loss points;
- Farming practices and infrastructure, such as seed supply, harvesting practices, shelling/threshing method, storage facilities, ease of access to markets (local, regional, etc.);

To investigate certain aspects of PHL in further detail, key informant interviews may be useful. Key informants have specialist knowledge about the geographical area of the study, the population involved or the technical issues at hand. These interviews can be held individually or in the context of focus groups. Typically, the following groups of persons may be involved:

- Traders
- Farmers and agricultural extension workers
- Government and NGO employees
- Community leaders

The organization of focus groups are a useful complement to farm household surveys, because they can provide information about sensitive subjects that are not easily addressed in a questionnaire survey and that can be used for cross-checking and validating. A focus group consists of people who have some characteristics in common and who can provide information on the matter at hand. The composition of the focus groups depends on the nature of the topic. Examples of focus groups include:

- Farmers who use similar agricultural systems and have similar assets, such as area of land cultivated;
- Traders who work with similar crops and have similar turnovers or storage problems; and
- Groups of women that are responsible for certain agricultural operations (rice harvesting, for instance)

Information from the preliminary assessment phase can be used to design a questionnaire for the second phase (main loss assessment) using a probability sample survey. The data and information collected in this preliminary phase can also be used to cross-check and validate the data gathered during the main loss assessment.

Main loss assessment.
Objective and scope: This must be framed according to the priorities established in the preliminary assessment. For example, the preliminary analysis may have identified that losses of maize on the farm were critical for the availability of cereals. These Guidelines recommend the use of a sample survey to collect data on PHL for the main loss assessment, irrespective of the level of the chain that is being investigated (farm or off-farm). This is to ensure the statistical representativity of the statistics. Within this survey framework, losses can be assessed based on farmer declarations, objective measurements or both. It is recommended to combine these two types of loss measurements using statistical pooling techniques.

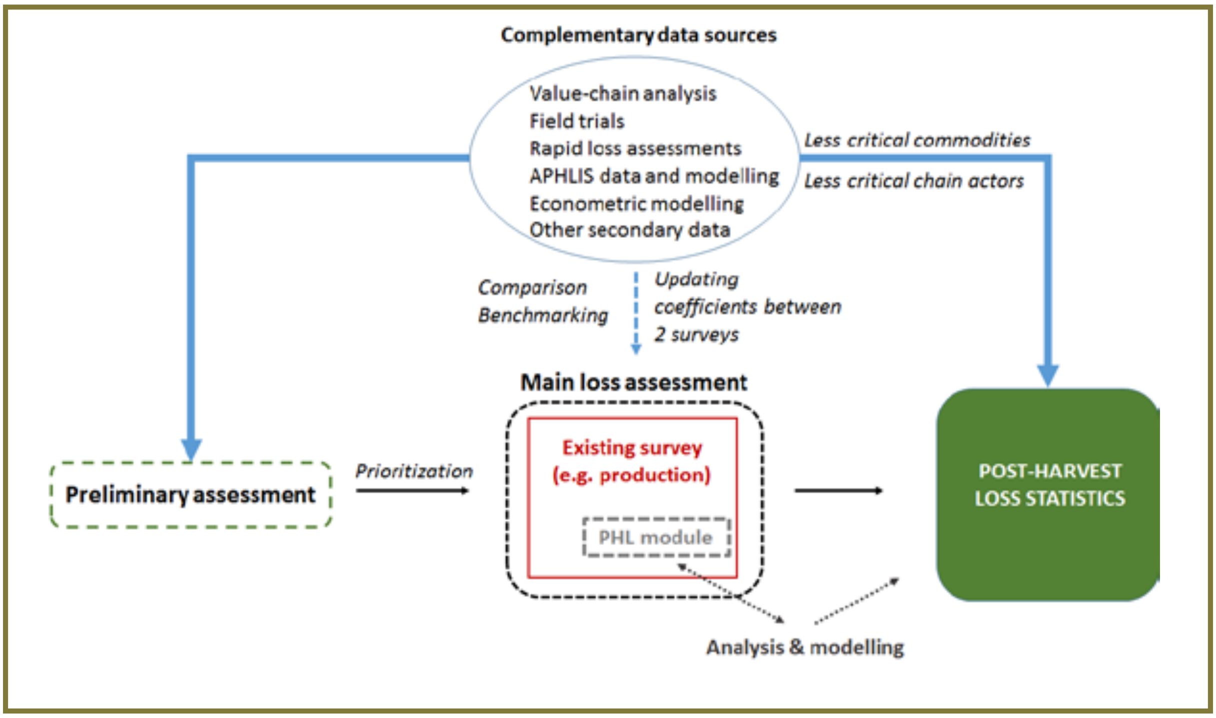
Integration with existing surveys: As a way to maximize cost efficiency and leverage different data sources, these Guidelines recommend using an existing agricultural survey as the main data collection vehicle for the main loss assessment. This means that PHL data collection can be "piggy-backed" onto any of these surveys in the form of additional modules, at a yearly frequency or lower. A good candidate to host a PHL module is the annual production survey (if it exists), especially if it includes a crop-cutting component, as loss data can be collected during the setting-up and harvesting of yielding plots. Even for the surveys relying exclusively on farmer declarations, questions on loss for different farm operations may be added to existing questionnaires. This recommendation to add PHL modules to existing surveys is not new. Indeed, FAO (1980) states that to "economize the collection of data on food-grain losses, it will be desirable to link such surveys with some other agricultural surveys such as crop-cutting surveys for the estimation of total food production, food consumption surveys, etc.".

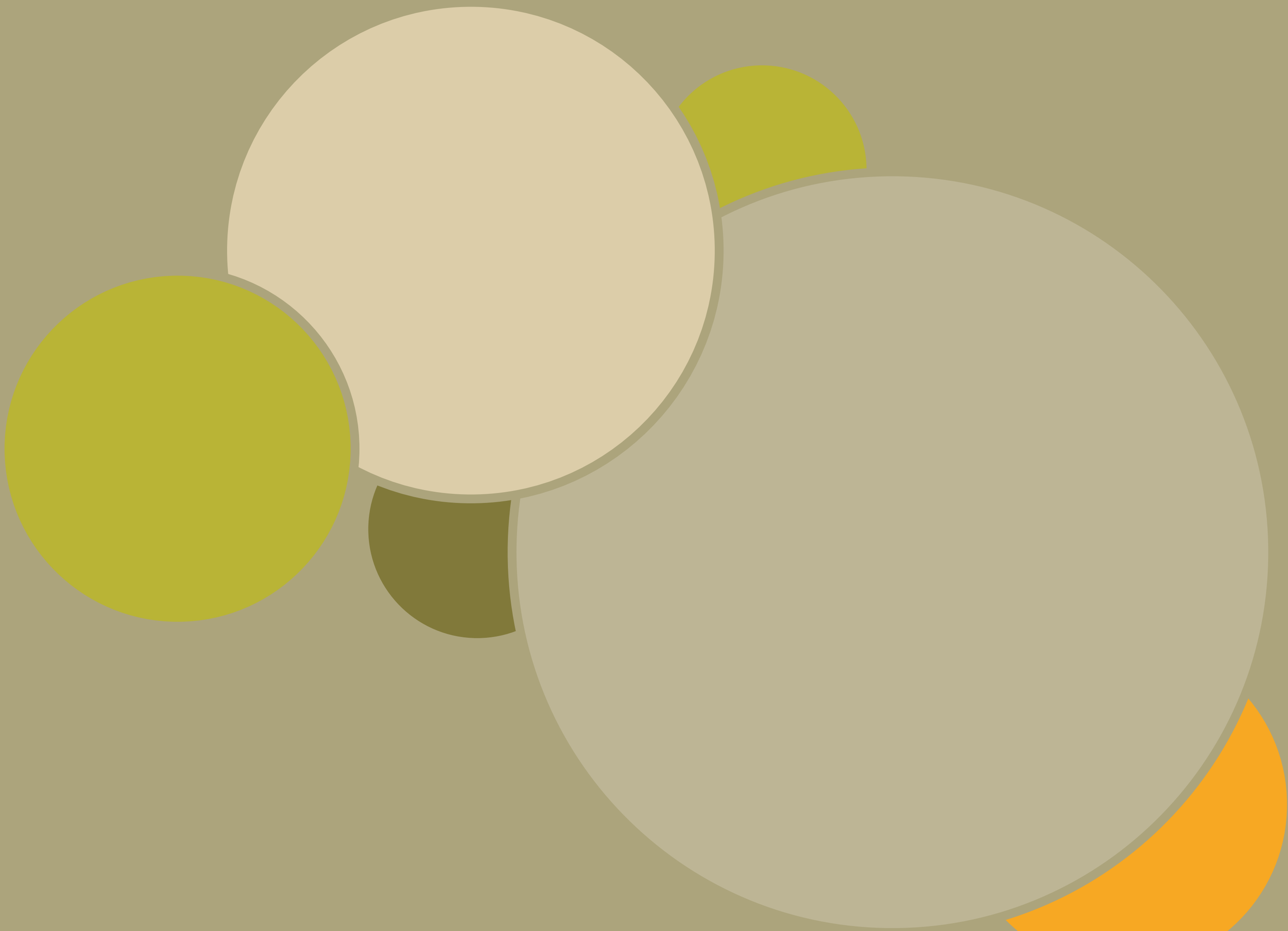
Frequency: Aggregate PHL parameters (for example, national averages), such as loss percentages by commodity, node of the supply chain and operation, are relatively stable from year to year, leaving aside extreme or particular events such as pest outbreaks. It is therefore not recommended to carry out a PHL survey module every year. A frequency of every three or four years is probably sufficient. Seasonal factors, as well as major agricultural variables that influence losses, such as climate conditions, crop varieties or farming practices, should be collected for every cropping season and may be used to adjust PHL parameters between two survey rounds, using appropriate models such as those used in the APHLIS framework or econometric models presented in chapter 7. The parameters of the model do not need to be re-estimated each year but only for each PHL survey round (for example, every three or four years), as new PHL data can be obtained to improve the significance of the correlations.

Establishing baselines: To establish a solid benchmark for loss parameters, the present Guidelines recommend that countries use their annual production surveys or large-scale PHL sample surveys to collect data on percentage losses for at least three consecutive years. The loss parameters compiled for the different years will then be averaged and the results used as the baseline. The next baseline could be established after each agricultural census, when fresh sampling frames are available. This will ensure that the baseline reflects structural changes in the farming system, such as increases in the mechanization rate or the adoption of more robust and pest-resistant varieties that may affect loss factors.

Complementary loss assessments.
The main loss assessment can be complemented by additional assessments based on a combination of primary and secondary data sources: results from lighter loss appraisals, such as the FAO 4S method or the RLAT, can be used for commodities or parts of the supply chain that the preliminary analysis may have not been identified as critical, or to identify more precisely the causes of losses and possible remedies. Model-based approaches using APHLIS-type methods or econometric modelling can be used to quantify the driving factors on losses or to update loss parameters obtained from the main loss assessment, between two survey rounds.

FIGURE 23. ILLUSTRATION OF A POSSIBLE MEASUREMENT FRAMEWORK FOR PHL.





10

Disseminating data on PHL

These Guidelines present and discuss several approaches to measure PHL, with a view to produce reliable statistics on food losses at the lowest possible cost. The value of statistics greatly depends on their availability and accessibility to final users. The way in which PHL indicators are compiled, disseminated and made available to the final users is an essential element of any statistical system, perhaps especially for complex and multidimensional topics such as food losses. These Guidelines would therefore be incomplete without a discussion on the dissemination of quantitative information on PHL. This chapter describes the different types of statistical products on PHL.

10.1 SURVEY REPORT

Survey or study reports are often the first product prepared after the collection of the data and calculation of the indicators. They should provide all information necessary for the user to understand the objectives of the survey and the methodology used to collect the data and calculate the indicators. They should also present the main results and indicators in such a way that they can be directly usable and interpretable by users, for example in the form of statistical tables or graphs.

These reports typically include the following information:

- Aim of the survey/study, scope, concepts, classifications and definitions used;
- Detailed description of the methodology: from the data collection approach (especially the sampling design, if applicable) to the compilation of indicators;
- Details of the organizational and practical aspects of the survey, such as organization of the fieldwork, staffing structure and validation rules. This is very useful to prepare future similar operations;
- Copies of questionnaires used;
- Main results, in the form of statistical tables, graphs and maps;
- Comparison with statistics from prior surveys or other sources; and
- Assessment of the reliability of results, qualitatively as well as quantitatively if possible (e.g. confidence intervals).

Examples of survey report are provided in Jha et al. (2015). This document, entitled "Report on Assessment of Quantitative Harvest and Post-Harvest Losses of Major Crops and Commodities in India", has the following contents: 1) Introduction; 2) Review of literature; 3) Survey considerations and schedules; 4) Data collection and scrutiny; 5) Data analysis; 6) Results and discussion, and; 7) Summary and conclusions. Another example of survey report is provided in the Global Strategy's publication titled "Field test report on the estimation of crop yields and Post-harvest losses in Ghana", referenced several times in these Guidelines (GSARS, 2017a).

Statistical information loses its value as it becomes outdated. To be useful for policy-making and food security, PHL survey reports must be disseminated as quickly as possible after data collection – as a rule of thumb, within six months of data collection. The publication lag depends on the scope of the study (which may be limited, for example, to a specific region or country) and the complexity of the data collection and measurement approach. For example, if physical measurements were made on the field and in specialized laboratories, requiring several visits to the farm or storage facility, more time will be necessary to validate the data and compile the indicators, as compared to a lighter approach based only on farmer declarations. Similarly, the implementation of complex estimation procedures such as variance estimation typically delays publication.

10.2 INDICATORS AND STATISTICAL TABLES

Aggregate indicators of PHL that are readily available, usable and interpretable by the users constitute a key output of any loss assessment. This section focuses on the type of indicators that can be disseminated and examples of dissemination practices.

Core loss indicators. The core indicators that can be expected from a survey or study on PHL are relative (percentage) and absolute (in kg) losses at each stage of the supply chain covered, eventually with an additional breakdown at farm level by type of operation (harvesting, threshing, etc.). These indicators will be presented by commodity and at different levels of aggregation (geographical or other) depending on the data collection scheme and sampling design. If possible, loss figures should be provided with a breakdown by actor (holding, retailer, warehouse, etc.) of the food chain as well as by the relevant factors that may affect losses, such as storage technique (for example, traditional or modern). The sampling design should allow, as much as possible, to present average loss indicators for a given commodity at the subregional level and not only at the regional or national level. If geographic data was captured during data collection, which is recommended, reporting should also provide map visualization to enhance the understanding of the information and maximize its utility.

Ideally, the average indicators should also be accompanied by measures of statistical reliability, such as standard deviations, coefficients of variation or confidence intervals. Below are several examples of loss indicators (presenting varying degrees of detail and breakdown) which may be regarded as best practices for the dissemination of statistics on PHL.

The first example (table 5) presents total percentage losses in India at national level during storage, broken down by supply-chain actors. In addition to the average percentages, the confidence bands are also provided (for example, 1.80-0.23 to 1.80 + 0.23 for storage losses occurring at the farm for paddy). In the second example (table 6), absolute loss indicators are presented by activity (on- and off-farm) and by country for maize in 2015. The average weight losses in tons are presented, without any quantitative indication of the statistical reliability of these estimates. This is probably because, as explained earlier, APHLIS estimates are mainly based on data gathered from the literature and are not generated from purely statistical processes. The third example (table 7) is taken from the survey report of the PHL pilot survey carried-out by the Global Strategy in 2016–2017. It shows percentage losses aggregated for all farm operations, from harvest to storage, by district. As the survey was made using random sampling techniques, confidence intervals were calculated.

TABLE 5. PERCENTAGE LOSSES FOR DIFFERENT ACTORS OF THE SUPPLY CHAIN IN INDIA.

Percentage Loss out of Total Amount Stored in Different Channels at National Level					
Crop	Storage Channels				
Cereals	Farm	Godown	Wholesaler	Retailer	Processing Unit
Paddy	1.80 ± 0.23	1.05 ± 0.26	1.38 ± 0.23	0.87 ± 0.16	0.39 ± 0.05
Wheat	1.40 ± 0.18	0.28 ± 0.08	0.57 ± 0.19	0.48 ± 0.12	0.62 ± 0.07
Maize	0.90 ± 0.45	0.46 ± 0.15	0.79 ± 0.23	0.81 ± 0.23	0.56 ± 0.19
Bajra	0.97 ± 0.12	0.53 ± 0.15	0.58 ± 0.16	1.09 ± 0.16	0.71 ± 0.15
Sorghum	1.05 ± 0.20	1.57 ± 0.15	1.22 ± 0.15	1.36 ± 0.25	1.04 ± 0.27

Source: Jha *et al.*, 2015.

TABLE 6. WEIGHT LOSSES (TONS) BY VALUE-CHAIN ACTIVITY FOR MAIZE.

Dry Weight Losses by Value Chain Activity - Maize, All data, 2015

	Harvesting/field drying	Platform drying	Threshing and Shelling	Winnowing	Transport to farm	Farm storage	Transport to market	Market storage
Burkina Faso	74,935	55,110	26,233	0	31,496	64,336	19,472	38,945
Ethiopia	6,514	4,791	2,280	0	2,732	9,663	1,693	3,386
Malawi	153,787	106,424	45,253	0	62,006	108,360	39,793	73,571
Nigeria	188	117	39	0	70	146	48	78
Senegal	11,475	7,149	2,359	0	4,289	7,059	2,949	4,736
Togo	40,520	29,800	14,185	0	16,994	43,375	10,529	21,059
Uganda	180,782	112,637	37,170	0	66,794	143,022	46,463	74,622
Zimbabwe	47,651	29,689	9,797	0	17,937	26,947	12,247	19,669

Source: APHLIS website (http://www.aphlis.net).

TABLE 7. HARVEST LOSSES AND PHL.

	Harvest and post-harvest losses (%)					
	Averages			Confidence intervals (90%)		
Main crop	All districts	Kintampo	Sawla	All districts	Kintampo	Sawla
Millet	5.0	12.4	4.4	[4.9 – 5.2]	-	[4.3 – 4.6]
Maize	9.5	12.3	2.1	[9.3 – 10.1]	[12.1 – 12.9]	[2.0 – 2.3]
Rice	5.1	5.2	4.0	[4.4 – 7.0]	[4.3 – 7.4]	[3.5 – 5.2]
Sorghum	2.9	11.1	1.8	[2.7 – 3.5]	[9.6 – 14.8]	[1.7 – 1.9]

Source: GSARS, 2017a.

These examples do not represent the wide array of indicators, dissemination formats, possible breakdowns and levels of detail. However, they provide a good indication of how the results of loss assessment studies can be disseminated.

Complementary indicators. In addition to loss estimates, dissemination can also encompass quantitative information on the key factors contributing to losses at critical points of the chain, as well as qualitative or quantitative information on the prevention and mitigating strategies. Examples of these complementary indicators include meteorological information, adoption rate of certain pest-resistant varieties, use of modern storage facilities (metallic silos, etc.), commodity prices along the supply chain (to estimate economic or value losses) and any other information that may help explain changes in loss patterns and add contextual information to the dissemination of the core indicators. This means that the tabulation plan and the reports derived from it should provide actionable cross-tabulations for food decision-makers concerned with practical issues of food loss prevention and reduction programs.

The frequency of dissemination of the indicators depends on the type of information and the study's objectives. Loss percentages can be considered as structural parameters that do not evolve significantly from one year to the next, for a given commodity and region. Loss percentages can be published on an annual or less than annual basis, depending on the data collection scheme that is being implemented. Average loss percentages coming from sample surveys conducted every three to four years can be updated annually using parameters such as climatic conditions. Absolute losses, however, can vary greatly from one year to the next given that they depend on area planted and yields, which are relatively volatile. Losses in quantity terms can be compiled on an annual basis or even at a greater frequency if, for example, a crop has several harvests within a year. Structural loss percentages may be multiplied by the estimated harvest (or quantities handled, for non-farm chain actors), a quantity that often comes from annual production surveys. Even absolute losses could be forecasted (which could help countries anticipate cereal import requirements, for example), by multiplying the loss ratios by the forecasted crop production.

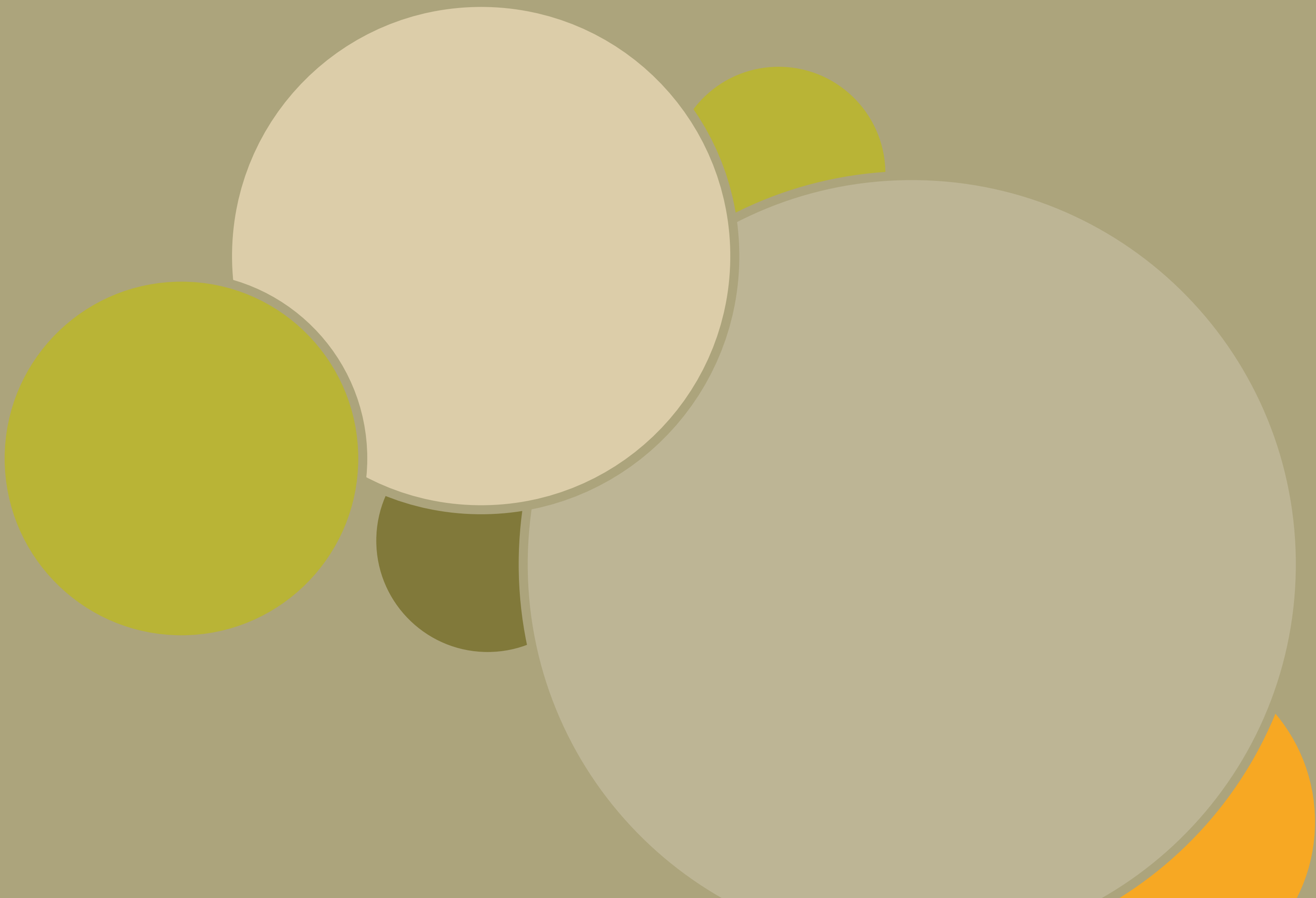
10.3 DATA SETS AND MICRODATA

The real utility of PHL survey data lies in its broad uses. In this perspective, the dissemination of anonymized data sets with information for each statistical unit, such as households, farms, fields or traders (such as microdata) offers users a wide range of analysis possibilities. While raw microdata may not be of immediate interest to policy-makers, who generally seek more aggregated and ready-to-use information, it is of direct interest to researchers within government, universities or colleges, the private sector and the public at large. Further to the wide array of possible analyses, for example on the determinants of losses and identification of the most effective prevention measures, the fact that data sets are made available with their respective metadata gives users the possibility to provide feedback on the quality of the data, its relevance with respect to the targeted uses and possible improvements. It also contributes to improve the relationship between data producers and data users.

In this regard, survey data has a definite advantage over other data sources in that in addition to generating the amount of information needed to compile aggregate indicators, it also generates a set of information that may be used for a wide array of analyses. This is less the case with data collection approaches that use qualitative approaches or that combine data from several sources, such as the APHLIS system. Indeed, the statistical outputs of the latter approaches are generally limited to aggregated indicators and study reports, which are of limited use for researchers and analysts interested in more in-depth work, involving econometric modelling for example.

Organizations interested in publishing microdata from PHL surveys, whether from pilot operations or full-scale activities, are encouraged to refer to the Guidelines that have already been written on this topic. For a quick overview of best practices on microdata dissemination, interested readers are referred to the "Micro-data dissemination best practices", a document published by the Statistics Division of the United Nations in 2014 and available online[1]. This document also provides references from international organizations and initiatives in data dissemination, management and reporting and links to online resources. Free and open-source dissemination platforms such as the Microdata cataloguing tool (NADA)[2], widely used by national statistics producers in Africa and elsewhere, can be used as a framework for quick and easy dissemination of PHL data from sample surveys. This type of platform allows for an easy description of the data set, variables and methodology (metadata) using international standards such as DDI/ISO.

1 https://unstats.un.org/unsd/accsub-public/microdata.pdf.
2 http://www.surveynetwork.org/software/nada.



11

Exploring future work: PHL of fruits and vegetables

11.1 COMMONALITIES AND SPECIFICITIES WITH GRAINS AND PULSES

PHL assessment studies for fruits and vegetables present both similarities and differences with respect to PHL assessments for grain. Similarities include the fact that:

- Surveys to collect PHL information can be conducted in a similar manner in terms of sampling design, questionnaire design and field data collection. However, the timing of data collection needs to be adapted to the seasonal pattern of horticultural production.
- Quantitative weight loss data may be collected and assessed for both domains.
- Similar regression approaches and other modelling techniques can be used to predict weight loss based on independent parameters such as humidity, temperature, farming practices and other environmental factors that may affect horticultural produce. Although the general modelling approach is similar, the structure of the model in terms of types of explanatory variables and their importance as explanatory factors of losses will differ depending on the commodity, grains or horticultural products.

Some of the main dissimilarities include:

- Differences in the structure and organization of the supply chains and the possible critical points for losses. For example, transportation from farm to market is known to be a major critical loss point for fruits and vegetables, but much less so for grains.
- In the case of PHL of fruits and vegetables, additional nutritional and other qualitative parameters are collected. The definitions of these indicators also differ, in some cases quite markedly, from their grains counterparts.
- Given the importance of qualitative parameters to measure PHL for horticultural products, measurements are often more complex and time-consuming, requiring additional laboratory work.
- The causes of losses are much more varied in the case of fruits and vegetables. The explanatory factors of losses vary widely according to the type of fruit or vegetable, as well as to the stage of the supply chain at which they occur. The most-listed damages in the literature include bruises, blemishes, cuts, rots in general, fruit borers, viruses, burns and cracking.

11.2 EXAMPLES OF PHL STUDIES FOR FRUITS AND VEGETABLES

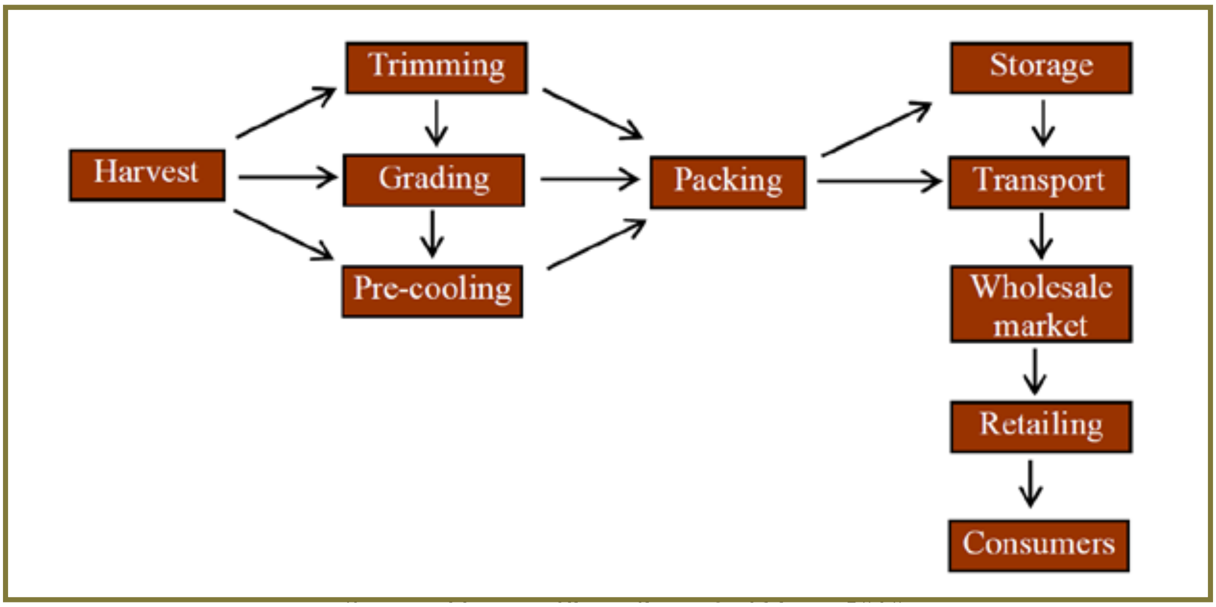
Three studies are briefly reviewed below to illustrate some of the most salient features of PHL measurement for fruits and vegetables.

Hassan, Chowdhury and Akhter (2010) conducted a survey to collect information on pre- and post-harvest practices for fruits and vegetables in Bangladesh and assess PHL (quantitative and nutritional) of fruits and vegetables at different stages of the supply chain.

The authors first reviewed existing estimates from the literature and highlighted that these vary widely both in developed and developing countries. Discrepancies between ranges such as 5–100 percent (NAS, 1978) and 20–40 percent (Wills *et al*., 2004) reflect the magnitude of the variability in the estimates.

One of the interesting features of this study is the characterization of the value chain of horticultural products (figure 24) and the identification of the different dimensions of losses for typical fruits and vegetables (table 8).

FIGURE 24. HORTICULTURE SUPPLY CHAIN.



Source: Hassan, Chowdhury & Akhter, 2010.

TABLE 8. PARAMETERS OF A TYPICAL PHL STUDY OF HORTICULTURE PRODUCTS.

Fruits/vegetables	Parameters/indicators
Mango	Colour, firmness, weight loss, disease incidence (DI), disease severity (DS), total soluble solids (TSS), sugars, Vit C, Vit A
Banana	Colour, firmness, weight loss, DI, DS, TSS, sugars, Vit C
Pineapple	Colour, firmness, weight loss, DI, DS, TSS, sugars, Vit C
Citrus	Colour, weight loss, DI, DS, TSS, sugars, Vit C, Vit A
Tomato	Colour, firmness, weight loss, DI, DS, TSS, Vit C, Vit A and lycopene
Okra	Visual appearance, Colour, weight loss, DI, DS, Vit C

Source: Hassan, Chowdhury & Akhter, 2010.

The measurement of loss is based on a combination of subjective methods (eye estimation) and physical measurements, while the qualitative parameters are defined over appropriate modalities and scales (firmness, visual appearance, etc.). This study pinpoints that the number of indicators involved in deriving percentage losses can be substantial.

Kwabena Asare-Kyei (2009) provides an interesting example of how quality losses arising during transportation can be estimated using regression modelling. In this study, Kwabena assesses the effect of transportation conditions during cargo on the quality of tomatoes, measured using firmness as the only dimension. The model relates firmness (a dependent variable) to microclimate conditions during transportation, characterized by temperature, humidity, light intensity and time after harvest, within a linear system of equations. This study shows that predictive analytics, particularly based on linear regressions, can also be used to measure PHL for horticultural products and provide decision-makers with timely loss information.

Msogoya and Kimaro (2011) provide an interesting illustration of how experimental trials can be used to assess PHL for fruits. The objective of this study was to determine PHL of mango ("Dodo" variety) at various stages of the supply chain and to assess the impact of certain post-harvest management practices (storage type, treatments) on losses. This research was confined to small-scale farms in Morogoro, United Republic of Tanzania.

Experimental designs are well adapted to carry out this type of detailed assessment. The measurement protocols will not be explored in detail here as they respond to concepts, designs and frameworks that have been described previously in these Guidelines. The interested reader can refer to the original paper. This work will only examine how the final measurements were performed, using a blend of objective and subjective methods: PHL were measured using the number of damaged fruits. Damaged fruits were further characterized based on the incidence of microbial decay (number of fruits with decay symptoms), decay due to fruit fly infestation (presence of larvae in the fruit pulp), mechanical injuries (number of fruits with broken peel or pulp), softness (physical measurement using a penetrometer) and shelf life (number of days when 50 percent of the fruits was considered unfit for human consumption). Some of the main results of this study are summarized in table 9.

TABLE 9. PROPORTION OF UNDAMAGED AND DAMAGED MANGO ("DODO" VARIETY) ALONG THE SUPPLY CHAIN.

Supply chain stage	Undamaged fruits (%)	Fruit PHL (%)
Harvest	97.4	2.6
Transport	89.4	10.6
Wholesale marketing (3rd day)	84.9	15.1
Wholesale marketing (5th day)	69.4	30.6

Source: Msogoya and Kimaro, 2011.

This case study is relevant to this report in two respects especially:

- It highlights how experimental designs and agronomic research techniques can be used to estimate quantitative as well as qualitative losses that might be otherwise difficult to obtain;
- The simple definition and relatively simple derivation of percentage PHL, equated here with the percentage of damaged fruits, as compared with PHL studies of food grains that generally provide losses in terms of a weight unit (kg or other).

Annex

ANNEX 1.1 TEMPLATES AND EXAMPLES OF VALUE CHAIN OUTPUTS

Map: Subdivisions of the country of the value chain (example of banana)

BANANA

Field studies in Murang'a, Kirinyaga, Meru, Kisii Counties

August – October 2012

Subsector information at a glance

Administrative Subdivision	Crop	Production (metric tons)		Number of farmers		Area planted (ha)	
		Subsistence farmers	Commercial farmers	Subsistence farmers	Commercial farmers	Subsistence farmers	Commercial farmers
Gaia Region	Cassava	500 000	300 000	20 000	1 000	10 000	5 000
	Maize	2 000	2 500	2 000	100	1000	500

Value chain description and critical losses

Administrative Subdivision	Crop/ commodity	Chain actors (numbers)	Chain processes	Technology (manual or mechanical)	Volumes handled (tons)	Quantitative losses (%)	Causes of losses
Zeus Region	Tomato	Retailers (200)	Market storage	Traditional	0.5	35	Bio-deterioration
	Banana	(3 000)	Transport	Mechanical	100.0	8	Bruising
			Ripening	Traditional	200.0	6	Mechanical
			Storage	Improved	100.0	10	Bio-deterioration

Supply-chain processes description

Banana

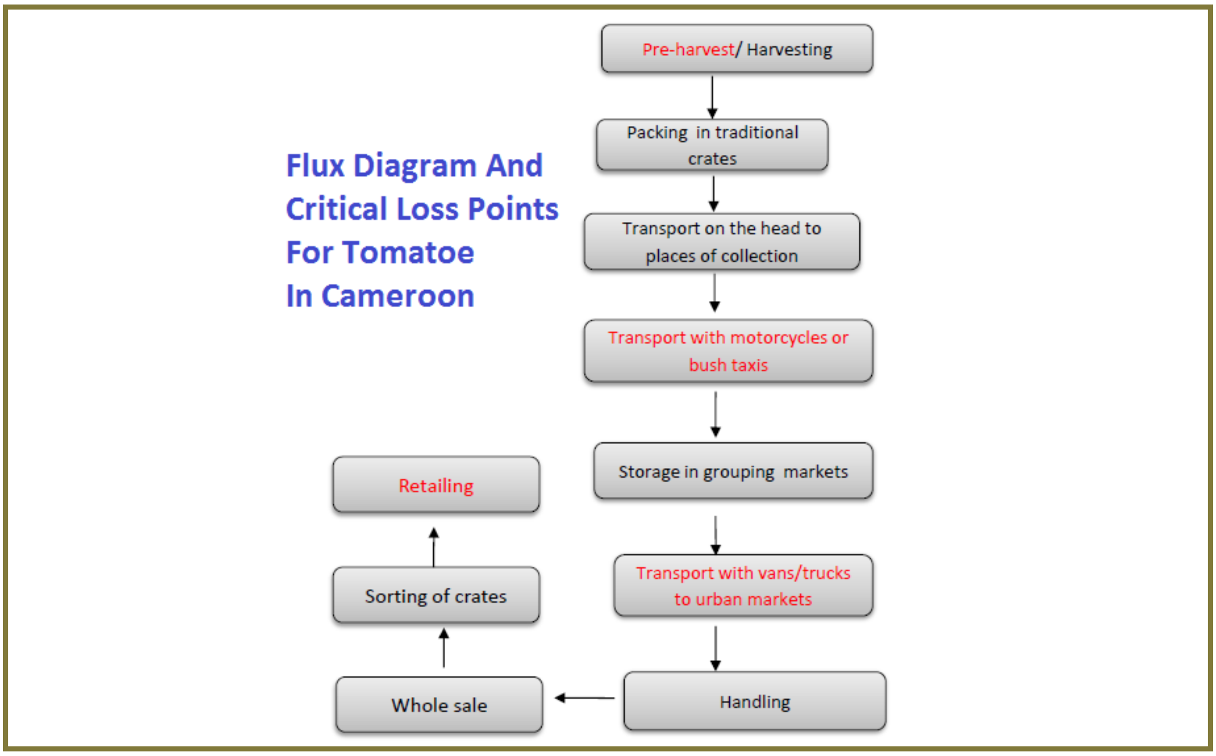
Ripening: A temperature of approximately 20 degrees Celsius is ideal for the ripening of bananas, with a relative humidity of around 80 percent. For most wholesalers, banana ripening is done under uncontrolled conditions.

Transportation: Transportation (which usually takes place in the evening, when temperatures are low) from the farm to the bulking site is performed using wheelbarrows, small vehicles, or motorbikes. The bananas are transported as whole bunches and no packing is done. The loading is done roughly into the truck so that the bunches stick to each other and can fit.

Storage: In the market area, there are only a few facilities with proper storage. Hence, traders use stalls made of corrugated sheet. The bananas are held for several days while selling continues.

Tomatoes

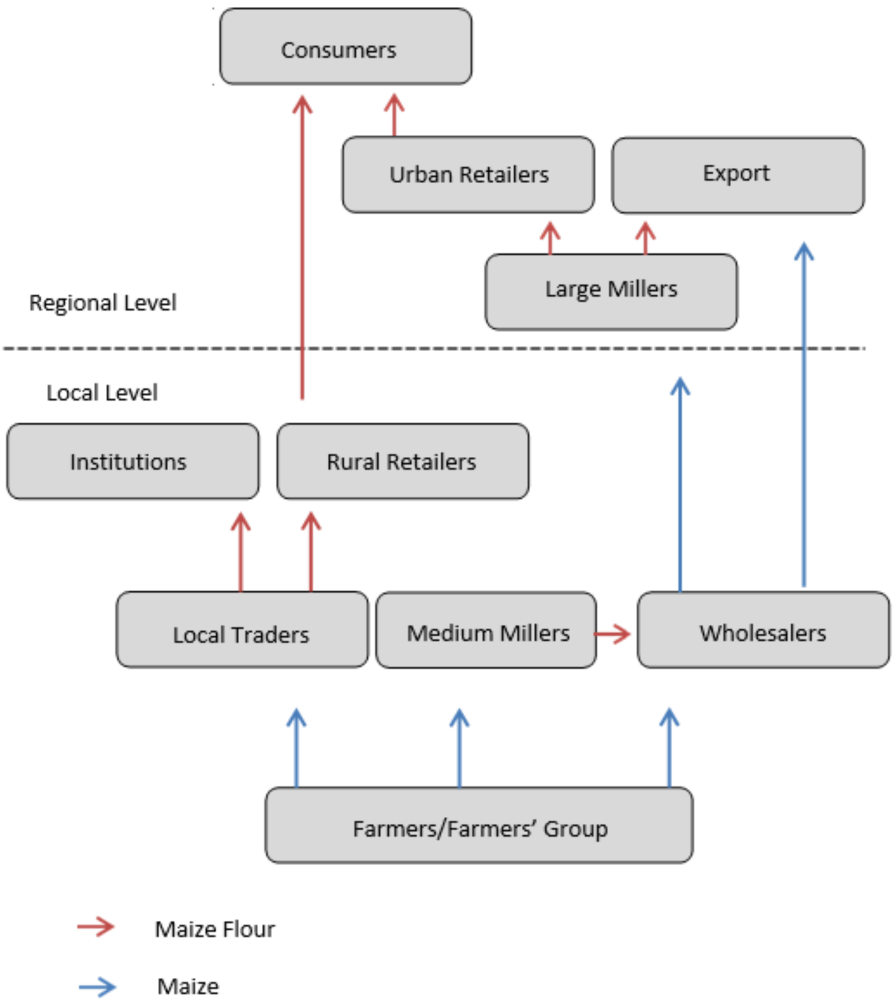
FIGURE 25. FLOW DIAGRAM OF THE CHAIN PROCESSES WITH HIGHLIGHTED CRITICAL LOSS POINTS.



Source: Drame & Lolo, 2014.

Diagram of chain actors and their linkages (maize)

Figure 1 (Mr. Ian DALIPAGIC, Dr. Gabriel ELEPU. 2014)



ANNEX 1.2 2016-2017 PILOT SURVEY ON PHL IN GHANA

A pilot survey was carried out in Ghana in 2016–2017 to test different measurement methods on crop losses (maize, rice, sorghum and millet) at farm level and to assess their relevance, cost-efficiency and replicability before recommending them to countries. The assessment framework was based on a sample survey carried out in two districts on a total sample of 560 farmers. Two measurement methods were tested: declaration-based estimates and estimates based on physical measurements.

The approach, methodology and findings of this pilot survey were presented in a report published by the Global Strategy in November 2017 and referenced in these Guidelines (GSARS, 2017a). Readers of these Guidelines are encouraged to read this report for details on the methodology and results. This annex presents the main findings of this survey, as well as the questionnaires used (some of which have been presented earlier in these Guidelines).

Main findings

The loss estimates compiled from this pilot survey are broadly in line with those available in the recent literature for similar grain crops, regions and countries. The estimates compiled from the literature are based on different measurement approaches (survey, non-survey, field trials, physical measurements, model-based estimates, declarative estimates, etc.).

This pilot survey also provided additional support to the fact that estimates based on objective measurements tend to be consistently higher than farmer-based estimates, a finding encountered in several studies. This is true for production and yields but also for crop losses, a topic that has benefited from far less attention in the objective measurement versus farmer declaration "debate".

One of the objectives of this pilot survey was also to assess the relationship between declaration-based estimates and estimates based on physical measurements. In this respect, the statistical evidence points to a weak apparent correlation between measured and declared losses; however, this relationship should be further analysed by including other explanatory variables.

Beyond the data and indicators provided by this pilot survey, useful insights have been gathered from the data collection and estimation process: measuring crop losses on the farm is a complex undertaking, for respondents and enumerators alike. It requires the use of skilled and experienced data collection teams and well-defined questionnaires, customized to the local context and reflecting actual farming practices. A thorough training and pre-testing of data collection tools is also necessary, especially when objective measurements are envisaged. Indeed, as their complexity is greater than for standard crop-cutting exercises, they require adequate training and appropriate measurement tools, such as weighting scales with the sufficient level of precision or spears to select grain samples. During this pilot survey, for example, the inadequacy of some of the weighing scales caused delay in the field activities and affected some of the measurements. This pilot survey also highlighted the need to adapt the data collection and measurement approach to better account for mechanized practices for harvest and post-harvest operations.

Questionnaires used

FARM HOUSEHOLD LISTING

QUESTIONNAIRE FH0: **FARM HOUSEHOLD LISTING AT SSU (VILLAGE LEVEL)**

A. Identification

AgZNo
01 02 03

DistrictNo
04 05 06 07

EaNo
08 09 10

Name of Supervisor:..
Starting Date:..................../...../2016
Ending Date:..................../...../2016

ID

B. Listing of farm households

HousehNo		Name of Head of Household	Address/Locality of Household and house number	CROPS PLANTED: Maize	Rice	Millet	Sorghum	Agr Hh	Agr Hh Serial No	
11	12			13	14	15	16	17	18	19

CODES

Crops Planted (Col 13, 14, 15, 16)

0. No

1. Yes

Agric Household (Col 17)

0. No

1. Yes

SAMPLED FARM HOUSEHOLDS

QUESTIONNAIRE FH1: SAMPLED FARM HOUSEHOLDS

A. Identification

EaNo
|_|_|_|
01 02 03

Name of Supervisor:..
Starting Date:.................../...../2016
Ending Date:.................../...../2016

B. Sampled Households

HousehNo		Name of Head of Household	Address/Locality of Household and house number	Crops Planted			
				Maize	Rice	Millet	Sorghum
04	05			06	07	08	09

CODES
Crops Planted (Col 06, 07, 08, 09)
0. No (Copy from Questionnaire FH0)
1. Yes (Copy from Questionnaire FH0)

FARM HOUSEHOLD DEMOGRAPHY

QUESTIONNAIRE FH2: FARM HOUSEHOLD DEMOGRAPHY

A. Identification

EaNo			HNo	
01	02	03	04	05

Name of Farmer:...
Name of Enumerator:..
Date:......../....../2016

B. Listing of household members

Pages .... Of ... Pages

Person	Serial No	Name of Person	RelHH	AGE		SEX	ACTIVE
06	07		08	09	10	11	12

CODES

RelHH (Col 08)
0. Head of Household
1. Spouse/Husband
2. Son
3. Daughter
4. Other Relative

SEX (Col 11)
0. Male
1. Female

ACTIVE (Col 12)
0. Not Active (on the holding)
1. Active (on the holding)

CROP LOSSES THROUGH FARMER DECLARATIONS

QUESTIONNAIRE FH3: **FARM GENERAL CHARACTERISTICS AND LOSSES BY INQUIRY**

PART0 - IDENTIFICATION

EaNo HNo

01 02 03 04 05

Name of Farmer:.......................................
Name of Enumerator:................................
Date:......./...../2016

PART1 - IMPLEMENTS

1.1 Ownership of OXEN	06	**CODES** 0. No 1. Yes
1.2 Ownership of PLOUGH	07	
1.3 Mechanised MILLING	08	
1.4 Mechanised HARVESTING	09	

PART2 - AREA (in acres)

		Number of fields
Total Farm Area	10 11 12 13	
Millet Area	14 15 16 17	18 19
Maize Area	20 21 22 23	24 25
Rice Area	26 27 28 29	30 31
Sorghum Area	32 33 34 35	36 37

PART3 - REVENUE AND OTHERS

3.1 Participate in Demo Plot / On Farm Trial	38
3.2 Non Agriculture Source of Income	39

CODES (for 3.1)
0. No
1. Yes

CODES (for 3.2)
0. No Income
1. Pension
2. Remittances
3. Wages
4. Other

PART4 - LOSSES FOR SELECTED OPERATIONS OF MAIN CROP (Inquiry)

4.1 Main CROP 40

	Equipment used	Quantity handled	Unit	Weight of unit in Kg	Quantity lost	Unit	Weight of unit in Kg	Causes of Los	Harvest period
4.2 Harvesting	41	42 43 44	u	45 46 47	48 49 50 51	u	52 53 54	55	56
4.3 Threshing/Shelling/dehusking	57	58 59 60	u	61 62 63	64 65 66 67	u	68 69 70	71	72
4.4 Winnowing/Sieving/Cleaning	73	74 75 76	u	77 78 79	80 81 82 83	u	84 85 86	87	88
4.5 Drying	89	90 91 92	u	93 94 95	96 97 98 99	u	100 101 102	103	104
4.6 Transport (threshing to store)	105	106 107 108	u	109 110 111	112 113 114 115	u	116 117 118	119	120
4.7 Storage	**Storage type** 121	122 123 124	u	125 126 127	128 129 130 131	u	132 133 134	135	136

CODES

Main Crop
1. Maize
2. Rice
3. Millet
4. Sorghum

Storage Type (Col 111)
1. Silos
2. Granaries
3. Pots
4. Cribs/barns
5. Room storage
6. Heaped on ground
7. Other

Equipment Used
1. Traditional
2. Modern - sheller
3. Modern - combined dehusker-she
4. Modern - other
5. Other

Unit (Col u)
0. No Unit
1. Bags
2. Basket
3. Bucket
4. Drums
5. Tins
6. Pieces
7. Koko bowl
8. Cocoa bag
9. Other local unit

Causes of Loss
1. Spillage
2. Physiological process (weight loss, wilting, softenin
3. Pest infestation (presence, boring insects)
4. Spillage + physiological
5. Spillage + pest infestation
6. No losses

Harvest period
1. Past
2. Current

FARM HOUSEHOLD LIST OF FIELDS

QUESTIONNAIRE FH4: FARM HOUSEHOLD LIST OF PLOTS

A. Identification

EaNo			HNo	
01	02	03	04	05

Name of Farmer:...
Name of Enumerator:..
Date:....../...../2016

B. Field listing

	CROPS PLANTED				AGRONOMIC PRACTICE						TYPE OF SEED				PESTS				FARMER'S ESTIMATE OF PRODUCTION																												AREA MEASURED (HA) Copy from FH5					
																			Maize							Rice							Millet							Sorghum												
FieldNo	Maize	Rice	Millet	Sorghum	Irrigation	Fertilizer	Comp/Manure	Insecticide	Weeding	Ploughing	Maize	Rice	Millet	Sorghum	Maize	Rice	Millet	Sorghum	Unit	How Many Units			Weight of Unit in kg			Unit	How Many Units			Weight of Unit in kg			Unit	How Many Units			Weight of Unit in kg			Unit	How Many Units			Weight of Unit in kg								Crop Cutting
06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
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CODES

Crops Planted (07, 08, 09, 10)
0. No
1. Yes

Type of Seed (Col 17, 18, 19, 20)
0. No Crop
1. Traditional
2. Improved
3. Improved + Traditional

Pests (Col 21, 22, 23, 24)
0. No Crop
1. No Pest
2. Insects
3. Viral
4. Others

Agronomic Practices (Col 11, 12, 13, 14, 15, 16)
0. No
1. Yes

Unit (Col 25, 32, 39, 46)
0. No Unit
1. Bags
2. Basket
3. Bucket
4. Drums
5. Tins
6. Pieces
7. Koko bowl
8. Cocoa bag
9. Other local unit

Crop Cutting (Col 58)
0. No
1. Yes

FARM HOUSEHOLD FIELD AREA

QUESTIONNAIRE FH5: FARM HOUSEHOLD PLOT AREA

A. Identification

EaNo HNo FieldNo

01 02 03 04 05 06

Name of Farmer:..
Name of Enumerator:..
Name of Supervisor:..
Date:............./...../2016

B. Field Sketch

Maize: 07

Rice: 08

Millet: 09

Sorghum 10

CODES

Col (07, 08, 09, 10)
0. No
1. Yes

Field Sketch

Area Planted (ha):

Perimeter (m):

		LENGTH		COORDINATES	
No.	SIDE	METERS	PACES	LONGITUDE	LATITUDE
1	A - B				
2	B - C				
3	C - D				
4	D - E				
5	E - F				
6	F - G				
7	G - H				
8	H - I				
9	I - J				
10	J - K				
11	K - L				
12	L - M				
13	M - N				
14	N - O				
15	O - P				
16	P - Q				
17	Q - R				
18	R - S				
19	S - T				
20	T - U				
21	U - V				
22	V - W				
23	W - X				
24	X - Y				
25	Y - Z				
26	Z - A				

QUESTIONNAIRE FH6: **FARM HOUSEHOLD CROP CUTTING**

A. Identification

Name of Supervisor:..
Date:..............................

EaNo **HNo** **FieldNo**

01 02 03 04 05 06

Area Planted (ha): 11 12 13 14 15
From FH5

Estimated Area for Harvest (ha): 16 17 18 19 20

Half Perimeter (ha): 21 22 23 24

Maize: 07
Rice: 08
Millet: 09
Sorghum: 10

CODES

Col (07, 08, 09, 10)
0. No
1. Yes

Date of Planting/Sowing: ..../...../2016

Date Harvest Started: ..../...../2016

Date Harvest Completed: ...../...../2016

B. Losses during harvesting

Method of Harvesting: 25 — 1. Manual 2. Mechanical

Date of Harvesting: ...../...../2016

YieldingPlotNo	Random Numbers								Crop	During manual harvesting of yielding plot																	
	Second				Third					Ears / Cobs				Raw Weight					Dry Weight					Kg/Ha			
26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
																								Office Use			

After manual harvesting : Grains/Cobs fallen of yielding plot																															
Ears / Cobs				Raw Weight					Dry Weight					Kg/Ha				Grains				Raw Weight					Dry Weight				
54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
														Office Use																	

Observation (for moisture content) : -------------------------

C. Losses during threshing/shelling

Method of Threshing/shelling: 86 — 1. Manual 2. Mechanical

All weight in grams

Type Threshing floor: 0. Unknown 1. Mud 2. Wooden 3. Cement

Date of Threshing/shelling: ...../...../2016

Type of threshing/shelling floor	**Number of bundles from yielding plot**	**Weight of grain after threshing/shelling bundles**	**Weight of straw obtained**	**Weight in 250g of straw**	**Number of grains in 250g of straw**
87	88 89	90 91 92 93	94 95 96 97	98 99 100 101	102 103 104 105

D. Losses during cleaning/winnowing

Method of Cleaning/winnowing: 106 — 1. Manual 2. Mechanical

Date of Cleaning/winnowing: ...../...../2016

Weight sample grain before cleaning	**Weight of grain after cleaning**	**Weight of straw/other material during cleaning**	**Weight in 250g of straw**	**Number of grains in 250g of straw**
107 108 109 110	111 112 113 114	115 116 117 118	119 120 121 122	123 124 125 126

STORAGE LOSSES BY OBSERVATION

QUESTIONNAIRE FH7: **FARM STORAGE LOSSES**

A. Identification

AgZNo

01 02 03

DistrictNo

04 05 06

EaNo

07 08 09

HNo

10 11

Name of Supervisor:...
Date:.................../...../2016..
Inquiry Period: .../…/2016 to .../…/2016
Name of farmer:…………………………….

B. Losses during storage (by observation)

CropCode	Name of Crop	Type Storage	Quantity stored beginning period			units	Additions during inquiry period			units	Sales/Consumption during inquiry period			units	Stock at the end inquiry period			units	Storage Duration (weeks)			Infestation	Attack by rodents	IDNo Batch Sample			Sample Dispatch Date					
12		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43

CODES

Type Storage (Col 13)
1. Silos
2. Granaries
3. Pots
4. Cribs/barns
5. Room storage
6. Heaped on ground
7. Other

Infestation (Col 33)
0. No
1. Yes

Attack by rodents (Col 34)
0. No
1. Yes

CropCode (Col 12)
1. Maize
2. Rice
3. Millet
4. Sorghum

Units (Col 17, 21, 25, 29)
0. No Unit
1. Bags
2. Basket
3. Bucket
4. Drums
5. Tins
6. Pieces
7. Koko bowl
8. Cocoa bag
9. Other local unit

STORAGE LOSSES BY PHYSICAL MEASUREMENTS (LABORATORY)

QUESTIONNAIRE FH8: **BATCH ID FOR SAMPLE TAKEN FROM FARM**

A. Identification

AgZNo
|__|__|__|
01 02 03

DistrictNo
|__|__|__|
04 05 06

EaNo
|__|__|__|
07 08 09

Name of Supervisor:..
Date:..................../...../2016..
Inquiry Period: .../.../2016 to .../.../2016
Name of farmer:…………………………….

Name of Laboratory Assistant:…………………………………
Date Received:…../../../2016

1. Keep one copy of this slip inside the sample bag
2. Tie another copy outside the bag
3. Keep one copy with the Supervisor for records.

HNo
|__|__|
10 11

B. Observations on samples sent by field staff for analysis in the laboratory

CropCode	Name of Crop	Type Storage	Weight sample drawn (grams)			Moisture Content (%)			Number of undamaged grains			Weight of undamaged grains			Number of damaged grains			Weight of damaged grains			IDNo batch sample			Date Sample Drawn					
12		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

CODES

Type Storage (Col 20)
1. Silos
2. Granaries
3. Pots
4. Cribs/barns
5. Room storage
6. heaped on ground
7. Other

CropCode (Col 12)
1. Maize
2. Rice
3. Millet
4. Sorghum

ANNEX 1.3 ALTERNATIVE METHODS TO MEASURE LOSSES OCCURRING DURING STORAGE

The volumetric method: This method seeks to compare the weights of a standard volume of damaged and undamaged grain and to measure the percentage loss using the following formula:

$$\%\ weight\ loss = 100.\frac{U-D}{U}.\frac{V_U}{V_D^2}$$

where U (respectively, D) is the grain weight of undamaged (respectively, damaged) grain, V_U and V_D the respective volumes of grain.

In practice, this method involves taking a representative sample of grain (or cobs, bundles, etc. which will then be threshed) from a given storage unit, separating damaged from undamaged grain and measuring the volume and weight of each sample. Damages made by grain-boring insects result in a lower density (mass in a given volume) of the sample of damaged grain as compared to the sample of undamaged grain.

This method can be standardized, by filling separate containers of the same volume with damaged and undamaged grain. The difference in weight should reflect the lower density of damaged grain, and is taken as the measure of weight loss.

The volumetric method is not exempt from biases, especially when damage levels are high. In this case, damaged and undamaged grains may fall and be packed differently in each container (for example, some damaged grains may break), leading to a significant difference in the number of grains required to fill a given volume and thereby distorting the density comparisons.

Modified Count and Weigh Method: The method described here is for maize, but a similar approach can be implemented for other grains. It consists of the following eight steps:

Step 1. A sample of maize cobs is taken in the same way as in the conventional method. According to experience, a sample of 30 cobs have been found to provide reasonably precise results.

Step 2. The cobs are shelled one by one, and the number of destroyed and missing grains is recorded for each cob and then summed over all 30 cobs to obtain the total number of destroyed and missing grains (TND). If desired, cob-related characteristics such as husk cover and grain type can also be recorded at this point. For consistency purposes, the criteria used to define "destroyed grains" should be clearly specified and rigorously followed. For example, destroyed grains can be defined as those which are crushed during shelling into fragments smaller than one third of a grain, or which passed through a 3.35 mm sieve in step 3. All such fragments must be thrown away to avoid double counting later.

Step 3. The shelled grains from each cob are sieved through a standard sieve set (for example, 3.35/2/0.85 mm mesh). If desired, the number and species of insects on each cob can be recorded at this point.

Step 4. The sieved grains from all cobs are then pooled. A typical pooled sample contains 7 000 to 15 000 grains and weigh from 1.5 kg to 3.5 kg. The pooled sample is weighed, and the weight recorded to the nearest gram. This is the Final Weight (FW).

Step 5. A riffle divider is used to subdivide the pooled sample several times to obtain two subsamples containing about 400 to 600 grains each. Remaining grains are discarded. The number of grains per subsample should be increased if there is a high proportion of damaged grain, because it is the total number of undamaged grains that primarily determines precision. A minimum of 50 undamaged grains per subsample is suggested.

Step 6. The grains in each subsample are separated into two groups, damaged and undamaged, by eye as in the conventional method.

Step 7. For each subsample, the groups of damaged and undamaged grains are counted and weighed as in the conventional method to obtain the quantities Nd, Nu, Wd and Wu.

Step 8. The percentage weight loss is then calculated using the following formula:

$$100 \times \frac{TND(W_d + W_u)W_u + FW(N_d W_u - N_u W_d)}{TND(W_d + W_u)W_u + FW(N_d + N_u)W_u}$$

Weight loss is calculated separately for the two subsamples and the average of these two values is taken as the estimated weight loss in the sample of cobs.

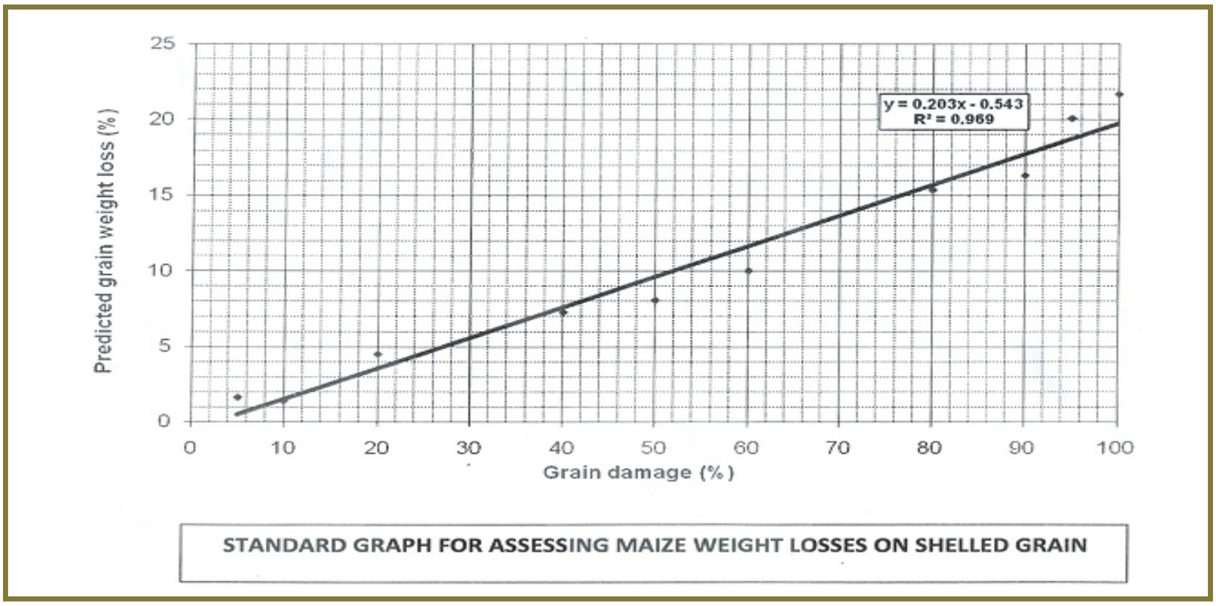
This method is quite cumbersome and therefore may not be recommended for large-scale assessment or surveys.

Converted Percentage Damage Method: This method is suitable only for assessing insect-related losses and provides a useful estimate for making a quick appraisal of losses. This method relies on determining the percentage of insect-damaged grain in a sample and its conversion to a weight loss using a predetermined factor. Although the method is liable to the same sources of error as the modified standard volume/weight method and the count and weigh methods, it has yielded good results in practice. Hence, it is recommended instead of guessing, when these two methods mentioned above cannot be used. Boxall (1986) suggests that once the relationship between percentage damage has been established by means of a laboratory experiment, a conversion factor could be calculated and subsequently used to determine the weight losses occurring in other samples of the same type of grain. Adams and Schulten (1978) recommended that the relationship between percentage damage and weight loss be established from the count and weigh method. This is why this method is subject to the same sources of error as the count and weigh method. The conversion factor is calculated from the formula by using the figures from the count and weigh technique. The principle is the same as that for visual scales (associating a certain percentage of weight loss to a certain degree of damage), but is restricted to insect-related damages, when visual scales can combine damages made by insects and molds for example, and is not accompanied by any visual aid.

Standard Chart Method: To estimate the weight loss for maize stored in grain form, the enumerator uses a standard chart. The procedure is as follows.
Step 1. A reference relationship between the number of damaged grain in a given sample and percent weight loss must first be established. This requires:

- The collection of grain samples of differing qualities from the farmers or traders some time in advance of the beginning of the survey fieldwork.
- Then, in a specialized laboratory, the analysts will separate, count and weigh the damaged and undamaged grain using the count and weigh methods presented previously, for each grain quality class.
- The percentage weight loss will be calculated using the methods presented above.
- A regression line is fitted between weight loss (Y) and the number of damaged grain (X), as shown in the illustration below.

FIGURE 26. STANDARD CHART FOR ASSESSING MAIZE WEIGHT LOSSES ON GRAIN.



Source: Malawi, 2011.

Step 2. In the field, the enumerator randomly selects separate samples of, for example, 100 grains each from the farmers' maize. The enumerator then places the grains in a litre plate to count the damaged grain. The process is repeated for the samples and an average number of damaged grain per 100 grains is established.

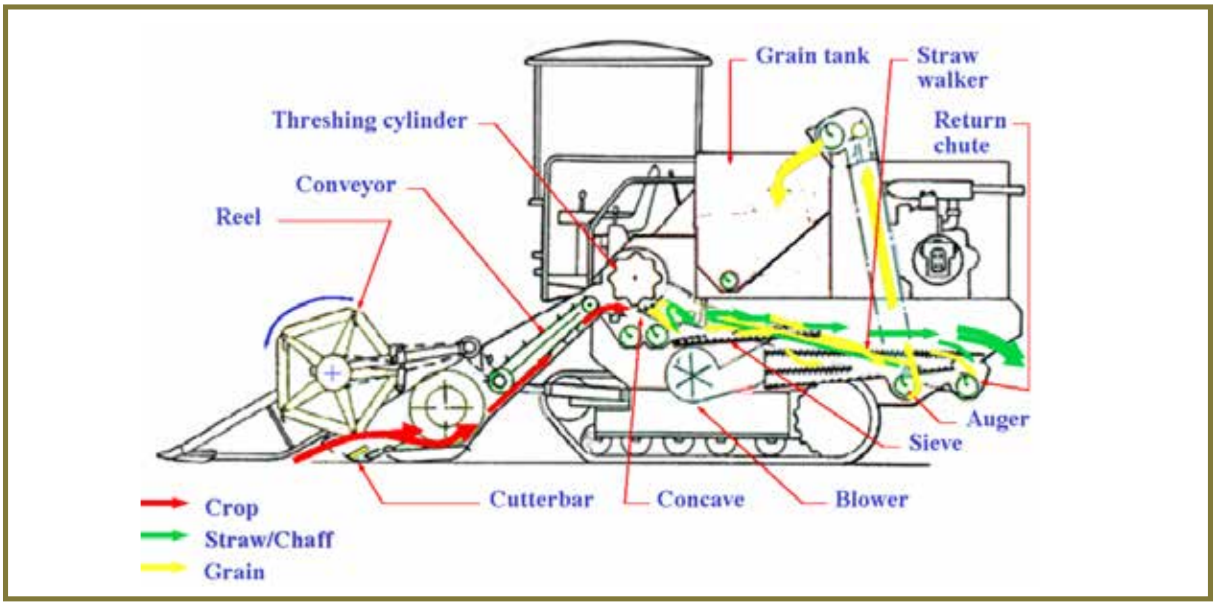
Step 3. The number of damaged grain is read off against a predetermined regression chart to find the percentage weight loss. For example, using the chart above, if the enumerator has established an average of 10 percent damaged grain from the samples he selected, he will attribute a percentage weight loss of 1.5 percent.

The visual scale method has proven to be rapid and easy to use, for both enumerators and respondents. The precision of the results was shown to be similar to that of competing methods. However, visual scales are only "rapid" in that the scales are prepared in the laboratory first and standard charts are established before the fieldwork takes place.

ANNEX 1.4 COMBINE HARVESTERS: MAIN TECHNICAL FEATURES AND SOURCES OF LOSSES

The operations of cutting, hauling, threshing and cleaning are all performed by a combine harvester. This agricultural machine works in such a way that the cereal crops are gathered in by the header at the front, which has a pair of sharp pincers called crop dividers at both ends. A slowly rotating wheel called the reel (or pickup reel) pushes the crops down towards the cutter. The threshing mechanism separates the grains from the straw, while the separating and cleaning equipment screens the grains and separates them from the chaff. This process is illustrated by figure 27 below. Losses due to damage and spillage occur during these operations and their amount depends on the type of harvester, its technical settings, the type of crop being harvested and its main characteristics, especially its moisture content.

FIGURE 27. SCHEMATIC ILLUSTRATION OF FLOW IN A CONVENTIONAL CYLINDER COMBINE.



Source: IRRI, 2015.

Manufacturers of combine harvesters provide instruction manuals that explain in detail how to precisely check for losses and adjust the machine accordingly. In particular, they indicate how the velocity of the threshing cylinder needs to be adjusted in function of the moisture content of the grain: as dry grains are more susceptible of damage than wetter grains, they require a lower velocity of the cylinder (Paulsen *et al.*, 2013). Other settings also influence losses at harvesting using combine harvesters, such as the space between the threshing cylinder and the concave opening: if the space is too narrow, excessive damage will occur; if it is too wide, the threshing will be incomplete.

ANNEX 1.5 MEASURING AND EXPLAINING PHL USING ANOVA

To present the statistical analysis, we take a simplified version of the experiment described by Appiah *et al*. (2011) with the two treatments (harvesting using panicles versus harvesting using sickles), but without stratification by variety. Losses at harvest have been measured on experimental fields using an RCBD design. The objective is now to assess if the effect of the harvesting method on harvest losses is statistically significant. The model is the following, using the same notations and definitions as those presented above:

$$Y_{i,j} = \mu + \alpha_j + \varepsilon_{i,j}$$

Where: $Y_{i,j}$ is the harvest loss measured for field i using the harvest method j, α_j is the effect of harvest method j on harvest losses, $\varepsilon_{i,j}$ is a random error term, $i = 1,.., n$ is the number of experimental fields $j = 1$ (if the harvest is done using panicles) or $j = :2$ (if harvest is done using sickles) and μ is the amount of losses independent of the field and harvesting method.
The objective is to test the statistical significance of the effect of the harvest method on harvest losses. In statistical terms, this means testing two hypotheses: *H0 (no effect):* $\alpha_1 = \alpha_2$ *vs. H1 (effect):* $\alpha_1 \neq \alpha_2$

These tests are carried out in three steps: decomposition of the total variance into the variance of each of its components, calculation of the test statistics, and decision. These operations are already programmed in most standard statistical packages (SPSS, R, STAT, SAS, etc.). The user only needs to specify the variable of interest (Y) and the explanatory factors (α). Additional parameters may be specified, such as the inclusion of interaction terms or the existence of random effects. We summarize the main steps of the calculation below.

Decomposition of variance:

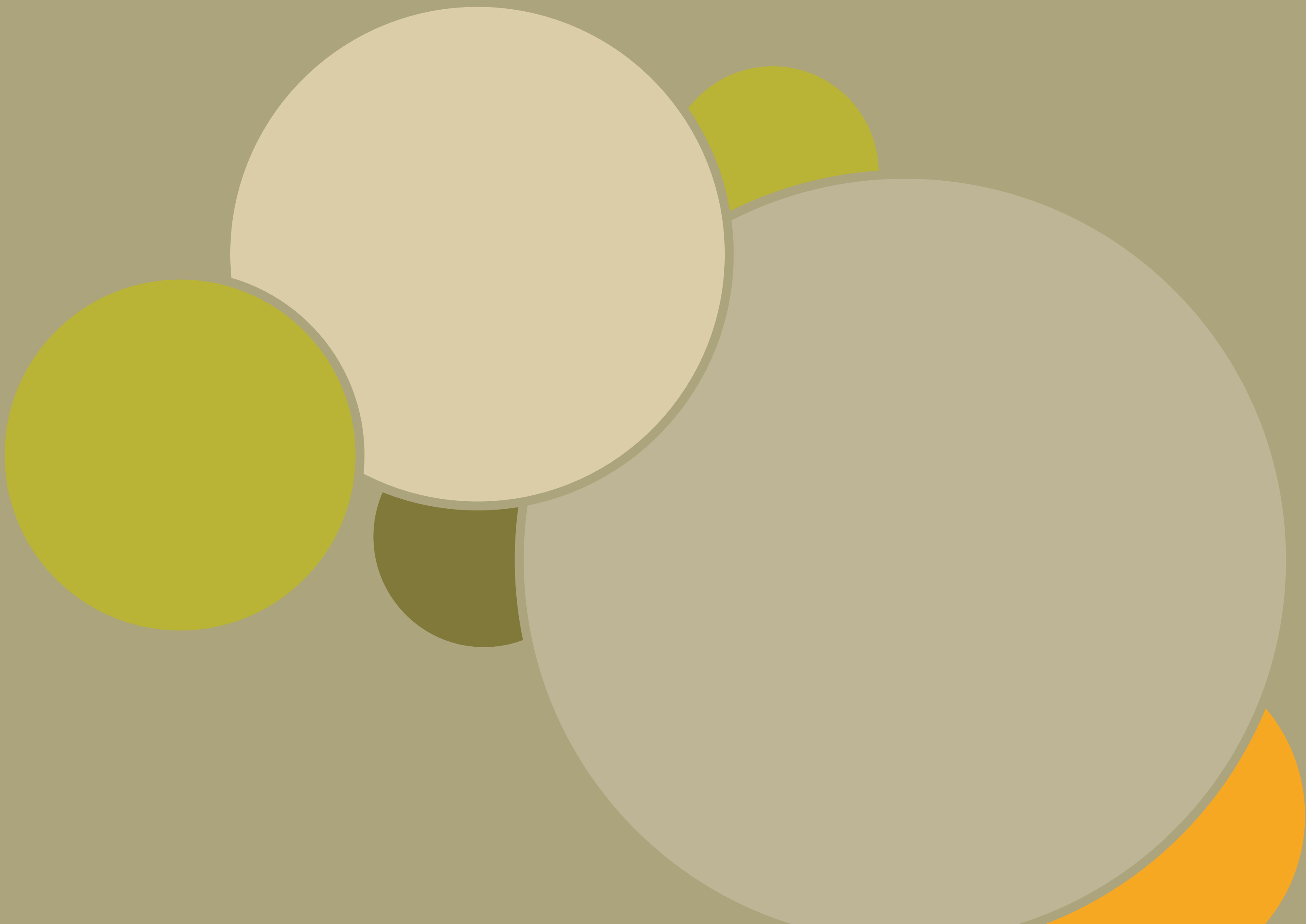
$$\sum_{i=1}^{n_j}\sum_{j=1}^{2}\left(Y_{i,j} - \bar{Y}\right)^2 = \sum_{i=1}^{n_j}\sum_{j=1}^{2}\left(\bar{Y}_j - \bar{Y}\right)^2 + \sum_{i=1}^{n_j}\sum_{j=1}^{2}\left(Y_{i,j} - \bar{Y}_j\right)^2$$

where n_j is the number of experimental fields harvested using method j, $\bar{Y}$ the average harvest losses for all fields and $\bar{Y}_j$ the average for fields harvested using method j. The term on the left is the total sum of squares (SST), the first term on the right-hand side of the equation is the sum of squares explained by the model (SSR) and the last term is the residual sum of squares (SSE, the portion of variability that is not explained by the model).

Test statistic: this is the ratio of the variability explained by the model to the unexplained variability.

$$F = SSR \Big/ \frac{SSE}{n-2}$$

Decision: Under *H0*, F follows a Fisher distribution. The conclusion on the test *H0* vs.*H1* is obtained by comparing F to the expected threshold of a Fisher distribution with 1 and $n - 2$ degrees of freedom and for a given risk level.



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