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Methodology to quantify food loss at primary production

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Foreword

This CEN Workshop Agreement (CWA 18410:2026) has been developed in accordance with the CEN-CENELEC Guide 29 "CEN/CENELEC Workshop Agreements — A rapid way to standardization" and with the relevant provisions of CEN/CENELEC Internal Regulations — Part 2. It was approved by the Workshop CEN/WS "Food loss quantification in primary production", the secretariat of which is held by UNE (Spanish Association for Standardization) consisting of representatives of interested parties on 2026-02-11, the constitution of which was supported by CEN following the public call for participation made on 2025-11-06.

However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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Introduction

Food loss or waste represents a significant share of global and European primary food production. According to the Food and Agriculture Organization (FAO) of the United Nations (UN), approximately 1,3 billion tonnes of food -equivalent to nearly one-third of all food produced for human consumption- are either lost or wasted every year along the food chain, from production to consumption [1].

Food loss alone accounts for about 13,2 % of food produced worldwide; however, this data only captures losses occurring after harvest, from farms to processing stages [2]. The limited attention given to food losses at the pre-harvest and harvest stages underscores the need for a more holistic and comprehensive understanding of the supply chain in order to define appropriate prevention strategies.

Preventing food loss not only improves food availability for all but also helps reduce the environmental footprint of agricultural production, supports resource efficiency, and enhances food system resilience.

The United Nations Sustainable Development Goals (SDGs), through Target 12.3, call for a 50% reduction in food waste per capita at the retail and consumer levels, along with a significant reduction in food losses along the production and supply chains by 2030. The European Union has progressively strengthened its policy attention to food waste reduction; however, EU definitions differ from those adopted by the UN, and harmonised definitions, reporting obligations, and monitoring approaches for food losses occurring in primary production remain under development. For this and other reasons, food loss has often remained under-reported and inconsistently measured across the European Union.

The FOLOU project, seeks to close critical knowledge and legal gaps by delivering robust methodologies for quantifying food loss at the primary production stage, based on available scientific evidence. This project has reviewed the definitions and concepts used in EU legislation, as well as international definitions, frameworks and methodologies related to food loss and waste, including those developed by FAO, UNEP and ISO. The project proposes a definition of food loss for primary production that is informed by relevant concepts, established in the EU legal framework applicable in the European Union, while also considering current voluntary frameworks.

NOTE The definitions contained in this document (see 4.1) are primarily aligned with concepts and definitions established in EU legislation, however, they also seek to ensure coherence and alignment with other European projects and international entities, thereby facilitating comparability of results and the generation of synergies across studies. The food loss definition provided by this CWA differs from UN/FAO food loss definition [3]. For specific links to international concepts developed by FAO and UNEP, see the FOLOU Food Loss Definitional Framework [4].

This CEN Workshop Agreement (CWA) formalizes a consensus-based approach developed through the FOLOU project, which is adaptable across various sectors and food commodity groups, while remaining cost-effective [5]. It specifies a methodology intended to harmonize the quantification of food loss occurring in the primary production stage, covering the agricultural, livestock, and aquaculture sectors.

The methodology established in this document provides a practical framework to support data collection, classification, and extrapolation from the plot or farm level to entire territories, based on specific criteria for each food commodity group.

Based on the FOLOU Food Loss Definitional Framework [4], the methodology is intended to be pragmatic, flexible, and scalable, thereby facilitating its implementation across diverse European and international contexts. Improved food loss data and information availability may enhance the general understanding of this issue and thus contribute to strengthening EU and global action to prevent and reduce food loss.

1 Scope

This document specifies a methodology for the measurement and quantification of food loss in food production in the primary sector, considering these five main food commodity groups:

— vegetables and fruits,

— cereals and pulses,

— roots and tubers,

— meat and dairy products, and

— aquaculture products.

It sets out the necessary steps for any entity (named hereafter "the organization") to quantify food losses within a specific site, territory and/or activity. This includes measurement planning and direct measurements at parcel, plot, farm, or pond level, as well as data extrapolation to regional, national or supra-national levels, when applicable.

This methodology is established within a framework that provides a definition of food loss that addresses existing gaps in European legislation.

This document also includes general requirements for using innovative technologies to facilitate the quantification of food losses in agricultural crop production.

This document is intended for the various stakeholders involved in food production, such as farmers, farmers' organizations, industries and distributors, public authorities at all levels, researchers, civil society organizations and others.

Practical case studies and supplementary information are provided in Annex A and B, respectively.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp/

— IEC Electropedia: available at http://www.electropedia.org/

3.1
feed
any single or multiple materials, whether processed, semi-processed or raw, which is intended to be fed directly to food-producing animals

[SOURCE: *Codex Alimentarius Commission (CAC/GL 81-2013)*, FAO/WHO [6]]

3.2
food (or foodstuff)
any substance or product, whether processed, partially processed, or unprocessed, intended to be, or reasonably expected to be ingested by humans

"Food" includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment. It includes water after the point of compliance as defined in Article 6 of Directive 98/83/EC and without prejudice to the requirements of Directives 80/778/EEC and 98/83/EC (...).

Food does not include:

— feed;
— live animals unless they are prepared for placing on the market for human consumption;
— plants prior to harvesting;
— medicinal products within the meaning of Council Directives 65/65/EEC and 92/73/EEC;
— cosmetics within the meaning of Council Directive 76/768/EEC;
— tobacco and tobacco products within the meaning of Council Directive 89/622/EEC;
— narcotic or psychotropic substances within the meaning of the United Nations Single Convention on Narcotic Drugs, 1961, and the United Nations Convention on Psychotropic Substances, 1971;
— residues and contaminants;
— medical devices within the meaning of Regulation (EU) 2017/745 of the European Parliament and of the Council.

Note 1 to entry: This definition differs from that used in ISO/DIS 20001 (under preparation) [7] and ISO 22000 [8].

[SOURCE: Regulation (EC) No 178/2002 (General Food Law Regulation) [9], modified — "shall" replaced by "does"]

Food also includes non-edible parts, where those were not separated from the edible parts when the food was produced, such as bones attached to meat destined for human consumption.

[SOURCE: Commission Delegated Decision (EU) 2019/1597 supplementing Directive 2008/98/EC (Measurement of food waste) – Recital 2 [10]]

3.3
food loss (FL)
any harvest-mature plant, animal or living being (both edible and non-edible parts), intended for human consumption, that is not successfully harvested, as well as food removed from the supply chain during post-harvest phase that does not become animal feed, by-product or food waste

Note 1 to entry: This definition differs from UN/FAO food loss definition [3] and extends beyond the EU definition of food (3.2). See the FOLOU Food Loss Definitional Framework for alignment with these frameworks [4].

[SOURCE: FOLOU, *Food Loss Definitional Framework* (2026) [4]]

3.4
food waste
all food as defined in Article 2 of Regulation (EC) No 178/2002 that has become waste (3.5)

Note 1 to entry: This definition differs from that used in UN/FAO [3].

[SOURCE: Directive (EU) 2018/851 amending Directive 2008/98/EC on waste [11]]

3.5
waste
any substance or object which the holder discards or intends or is required to discard

[SOURCE: Directive 2008/98/EC on waste [12]]

3.6
by-product
substance or object resulting from a production process the primary aim of which is not the production of that substance or object is considered not to be waste, but to be a by-product if the following conditions are met:

a) further use of the substance or object is certain;

b) the substance or object can be used directly without any further processing other than normal industrial practice;

c) the substance or object is produced as an integral part of a production process; and

d) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

Note 1 to entry: This definition differs from that used in ISO/DIS 20001 (under preparation) [7].

[SOURCE: Directive 2008/98/EC on waste [12]]

4 Food loss quantification

4.1 Food loss definitional framework

This document defines food loss as any harvest-mature plant, animal or living being (both edible and non-edible parts), intended for human consumption, that is not successfully harvested, as well as food removed from the supply chain during post-harvest phase that does not become animal feed, by-product or food waste [4].

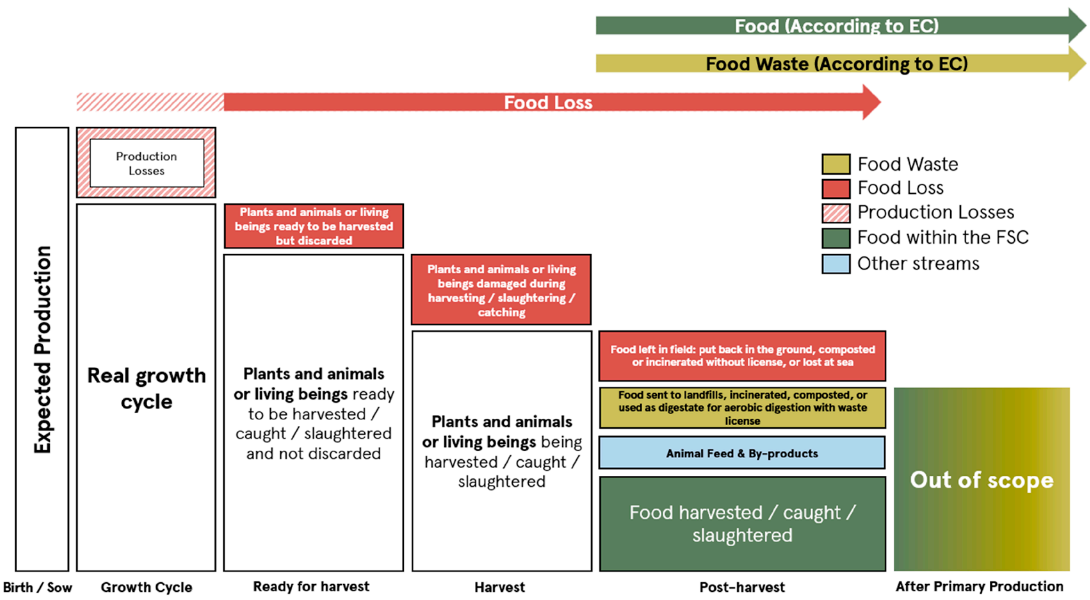

Figure 1 — The Food Loss definitional framework

The food loss (3.3) definition applies from the moment when the food is ready to be harvested/slaughtered/caught until the moment when it is harvested/slaughtered/caught, including the pre-harvest, harvest, and post-harvest stages. All food initially -or at some point- intended for human consumption is included in the definition, regardless of whether it is avoidable or not.

The "ready to be" moment implies that the product is edible and complies with market dynamics. This moment applies at the following specific moments for each of the following food commodity groups:

- Agriculture (vegetables and fruits / cereals and pulses / roots and tubers): from the moment when the products are ready to be harvested until the moment when they are -or could be- harvested.
- Meat: from the moment when the animal is ready to be slaughtered -according to each region and situation- until the moment when post-mortem inspection approval is granted. This includes pre-slaughter losses, handling and transport losses, and slaughter-related losses.
- Milk: from the milking moment to the moment when the milk is tested and accepted or rejected in the dairy plant, immediately prior to the processing stage. This includes on-farm, storage, and transport losses.
- Aquaculture (fish): from the moment the fish reaches marketable size (e.g., approximately from 3 kg for salmon) until the moment the fish is slaughtered.
- Aquaculture (molluscs): from the moment the molluscs reach marketable size (e.g., approximately 5 cm for mussels) until the moment when the molluscs are harvested.

4.2 Measurement planning

4.2.1 General

As a general framework for measuring food losses, a measurement plan shall be designed to guide the quantification process, including the following elements:

- Scope definition,
- Perceptual quantitative data,
- Sampling strategy,
- Food loss categories.

4.2.2 Scope definition

The organization shall define the scope within which food loss will be quantified. In this phase, it is recommended to collect official statistical information from the area where the measurement will take place. The scope of analysis includes:

a) Food loss definition:

The definition of food loss used in the study shall be specified. In case the study contains different food loss definitions or includes food waste data, food loss data according to this document shall be identified separately.

b) Territory:

The geographical scope where the organization decides to quantify food losses could be a plot, a farm, a site, a municipality, a region, a country, or a supranational area. In the case of territories, the selected areas should have similar statistical systems that allow for the collection and extrapolation of data, keeping their homogeneity and comparability. It is recommended to identify the territorial level using at least NUTS codes level 3, when applicable, or otherwise the closest regional administrative classification [13].

c) Activities and food commodity groups:

The primary production activities where the organization decides to quantify food loss data shall be determined according to the Statistical Classification of Economic Activities in the European Community (NACE) [14] classes (4-digit codes) to allow for data extrapolation to equivalent activities. In addition to NACE Class, the activity to be measured should be at least disaggregated into a 5-digit code of the Classification of products by Activity (CPA) [15].

In regions outside the European Union, International Standard Industrial Classification of All Economic Activities (ISIC) [16] could be used instead of NACE classes, and Central Product Classification (CPC) [17] instead of CPA codes (detailed information is provided in Annex B: Classification of Economic Activities).

This document establishes specific requirements and recommendations to calculate food loss in the following food commodity groups:

- Vegetables and fruits,
- Cereals and pulses,
- Roots and tubers,
- Meat and dairy products,
- Aquaculture.

When applying the quantification requirements (see 4.3), the appropriate food commodity group shall be selected for each activity, and the product code shall be referenced in the food loss study.

d) Available data:

In this initial phase, if the scope of the study covers an area broader than the farm, plot, or site level, the organization shall gather official statistical information -or, where such information does not exist, the most reliable available data- on activities and primary production in the territory (see Annex B), including:

- Number of farms, categorised by 4-digit NACE/ISIC Classes and, if available, further disaggregation into CPA/CPC Codes. When conducting studies at the national or supranational level, it is also recommended to obtain farm information disaggregated by municipalities, provinces or regions;
- Extent of cultivated land in the study area;
- Production volume of each type of crop/activity in the study area.

With this baseline information, the organization should identify priorities for the food loss quantification process (see Annex B, paragraph d.), especially in two aspects:

- Which economic activities within primary production and which types of crops/livestock/aquaculture are most relevant in the territory, and thus of higher priority in defining the measurement processes for losses;
- Which areas of the territory have a higher concentration of these economic activities/crop types to facilitate efficient measurement of these losses.

e) Sites:

The specific area(s) where food loss will be measured may include primary production sites such as agricultural farms, parcels, plots, or aquaculture facilities, and they can be studied individually or by groups of farms, facilities, etc. The organization shall gather the information indicated in the next subclause (4.2.3) regarding the site and the production characteristics.

4.2.3 Perceptual quantitative data

When defining the measurement plan, the organization shall gather detailed information on the sites or plots, with the objectives of understanding the context where losses occur, the main characteristics of the crop/site and the production processes, and the causes of food loss.

This process shall be conducted through an interview or questionnaire to producers, which at a minimum includes:

- Basic data of the plot/site: location, hectares/capacity, crops/species, methods;
- Characteristics of the production: average and estimated production/yield, proportion of marketable produce, and marketable parameters;
- Characteristics of the process: harvest process, number of cuts/collections/slaughters;
- Food loss: declared quantity and reasons for food loss.

The organization shall use this interview or questionnaire to obtain perceptual quantitative information (self-reported estimates) from the producers/farmers. This information shall only be treated as complementary and used to contextualise and cross-check empirical measurements, noting potential recall and bias. Semi-structured interviews or questionnaires may give the opportunity to expand upon or raise new unforeseen topics, such as the decision of the time to harvest, the market remuneration of different produce categories, or the market behaviour regarding food quality parameters. Criteria used to identify marketable produce shall also be identified and registered at this stage.

4.2.4 Sampling strategy

4.2.4.1 General

This subclause specifies the minimum sample requirements and recommendations for each food commodity group and crop type.

The organization shall design and document a sampling strategy based on the information obtained in the previous steps, with the objective of obtaining the most representative data. If complete operational records on food loss exist (e.g., daily loss logs), these shall be used as the primary quantification source instead of on-site sampling. Data completeness, definitions used, and any conversion factors applied, shall be documented.

When defining the sample, the organization shall consider the following elements:

- Food commodity group,
- Type of crops or animal species,
- Location: address and zip code,
- Working method agreement with the farm owners/managers,
- Size of the plot, farm, or site,

- Farming practices: conventional, organic or agroecological,
- Measurement method: manual or technology-based,
- Number of harvests/cuts per campaign and duration.

The information on the food commodity group, the type of crops or species and the location has been detailed in the previous subclause (4.2.2.).

For all food commodity groups, the organization shall sign an agreement with the company (producer) detailing the conditions of the study (sites, days, contact persons, sampling procedures, data reporting and confidentiality disclosures).

Considering the size of the plot, farm, or site, a portion of the total area shall be selected as a measurement sample. The organization shall calculate the percentage of the portion covered by the sample in relation to the total plot, farm, or site. Its main farming practices (> 50 %) should also be indicated as conventional, organic or agroecological.

For manual measurements, the sampling percentage shall be above 0,1 % of the plot, farm or site to be considered a sufficient sample according to the following criteria:

- Percentages below 0,1 % of the total: insufficient measurements;
- Percentages between 0,1 % and 1 %: sufficient but limited measurements;
- Percentages between 1 % and 10 %: significant measurements;
- Percentages above 10 %: desirable measurements.

For technology-based measurements (e.g., UAV (Uncrewed Aerial Vehicle) imagery, remote sensing, AI-assisted detection), the sampling percentage cannot be fixed in advance because it is restricted by several constraints, such as drone battery capacity, flight duration, weather conditions and regulatory limits. Coverage should be as extensive as operationally feasible, and full-plot mapping is recommended when conditions allow. Where the entire crop cannot be covered, the percentage of the crop covered shall be reported, together with the reason why full coverage was not achieved. The percentage of the crop covered shall not be less than 10 %.

4.2.4.2 Agriculture

For manual measurement, random samples shall be selected, covering an area equivalent to the defined percentage of the sample in relation to the total plot area. These measurement processes shall cover a minimum of 0,1 % of the total plot, and they should be conducted as specified below per specific crop type:

- Vegetables: as a recommendation, 3 rows of 15 m should be sampled or a number of areas that cover in both cases at least 0,1 % of the plot.
- Roots and tubers: for crops such as potatoes, sweet potatoes, onions, carrots, beets and similar crops, sample areas of 1 m^2 should be selected and excavated to a minimum depth of 15 cm.
- Fruits: an area or alternatively a number of trees in the plot should be selected that represent the selected sample in relation to the total plot.
- Cereals and pulses: as a recommendation, multiple 1 m^2 areas should be sampled so as to cover up to 0,1 % of the total cultivated area. As an alternative, a sample of 10 plants in 5 areas per hectare may be collected, and the yield components may be analysed to estimate the attainable yield [18].

The sampling area shall be selected randomly and include the most representative areas of the plot, without excluding less significant areas. It is recommended to consider the homogeneity level and size of the plot when deciding the number of samples (e.g., the greater the heterogeneity and/or the size, the higher the number of samples required). It is also recommended that the farmers themselves help identify these areas. The sampling methodology and justification for the selected areas shall be described in the management plan.

When defining the sampling area, it should also be considered the regularity of the crop distribution to be quantified, i.e., the similarity of row spacing and within-row spacing.

In those cases where part of the crop will not be harvested, random sampling shall be conducted in both areas (harvested and non-harvested), covering an area proportional to the size of the total plot that each one occupies.

E.g. Measurement of a field with two clearly distinguishable zones (1 % sampling)

In the case of a field of 1,5 hectares (or 15 000 m^2), 1 % of 1,5 hectares would amount to 150 m^2. The sampling area shall be distributed between the 2 zones:

a) Harvested zone (2/3 of the plot): This represents 66,67 % of the total area, so the sampling area will be:

   150 m^2 × 66,67 % = 100 m^2

b) Unharvested zone (1/3 of the plot): This represents 33,33 % of the total area, therefore the sampling area will be:

   150 m^2 × 33,33 % = 50 m^2

The sampling area or sampled trees shall be marked with an appropriate system (e.g., tape, tree tags) that endures throughout the harvest and causes minimal interference with the production works. A drawing/image of the plot with the selected area shall be included in the measurement plan.

The number of harvests/cuts per campaign and duration shall be considered when designing the sample strategy. According to the seasonality and production profile, it is recommended to measure the quantity of losses generated in periods of high productivity. It is also recommended to conduct some measurements during periods of low productivity to estimate the total amount of losses generated throughout the year.

For technology-based measurements, different approaches can be used depending on the remote sensing technology selected for measuring crops and orchards[1].

- Semi-automated approach: it uses technology such as high-resolution cameras mounted on drones (UAVs) or tractors for collecting imagery. This imagery or video shall then be analysed by the organization to count and register food losses. The data analysis can be processed on separate images, but it can also be used software (structure-from-motion software) to first create georeferenced maps (orthomosaics). It is only possible for crops and fruits that are clearly visible from aerial or tractor views, even though corrections for occluded fruits are required. Sufficiently high detail is needed, depending on the crop type –poor data quality or limitations in resolution can lead to uncertainty.

- Automated approach: data shall be captured by devices such as high-resolution RGB (Red-Green-Blue) cameras. As for semi-automated methods, the images or video captured can be analysed as such or can first be processed into orthomosaics. The data shall then be analysed automatically using deep learning (AI) algorithms, automatically registering and counting crop losses, and residues left in the field. The automated approach allows for the use or integration of other sources of information (e.g., multispectral or thermal cameras, LiDAR -light detection and ranging- data). According to

[1] Innovative technologies enable the assessment of food loss both in terms of quantity and quality.

existing experiences, the automated approach has been developed for two case studies: cauliflower (an example of a vegetable crop) and apple/oranges (orchard fruit crops).

4.2.4.3 Meat and dairy

The totality of meat and dairy losses shall be registered, and on-site sampling does not apply when measuring a farm food loss. Accounting for losses in meat and dairy at the direct measurement stage should be done by cumulative record of daily losses, rather than through sampling procedures.

4.2.4.4 Aquaculture products

The totality of the losses for fish shall be measured, and on-site sampling does not apply when measuring a farm food loss. Accounting for losses in fish aquaculture at the direct measurement stage should be done by cumulative counting of daily losses, rather than through sampling procedures.

Food loss quantification for molluscs at marketable size ("ready to be harvested") requires a minimum sample of 0,1 % of the total potential production of the selected farm, in terms of cultivation mesh sleeves. A minimum of 3 sampling areas shall be identified at different distances from the coastline. Three sleeves shall be sampled from each site.

4.2.5 Food loss categories

At the planning stage, food loss categories shall be defined to classify food loss produce once collected. The categories depend on the food commodity group, the objectives of the study, the preferences of the producers, and other factors. It is recommended to use the following categories [19]:

- Edible and marketable: products that are perfectly edible for consumers and meet all aesthetic requirements for sale as fresh produce, particularly the calibre.
- Edible but not marketable: products that are edible, but the markets reject them and do not consider them suitable for sale and/or do not meet European regulations for sale, particularly regarding aesthetic criteria like calibre.
- Non-edible and not marketable: products that, for various reasons (severe mechanical damage, pests, diseases, immaturity, etc.), are unfit for human consumption, regardless of their calibre and other aesthetic parameters.

The producers shall define the parameters for what is considered fresh marketable produce and the criteria shall be included in the management plan.

4.3 Measurement process

4.3.1 General

Food loss shall be measured for each food commodity group according to the criteria specified in this subclause. When applicable, it shall be measured with calibrated scales and expressed in kilograms or metric tonnes.

4.3.2 Agriculture

4.3.2.1 Manual direct measurement

4.3.2.1.1 Single-cut vegetables

Quantification of food loss in vegetables shall be assessed through a minimum of one on-site measurement after harvest. Harvest losses shall be measured within 3 days from the moment of harvest, avoiding any interference with harvesting operations. All the remaining vegetables on the ground and from the crop shall be collected. In case that vegetables are not harvested, the time when the measurement is conducted should be registered.

In case that pre-harvest and/or post-harvest losses are measured, the following conditions are required:

- Pre-harvest losses shall be measured 1 to 3 days before harvesting. Only the products that have been removed from the plant or the soil shall be weighed (or those that the farmer hypothetically indicates can be uprooted). All the products collected shall be removed from the area.

- Post-harvest losses shall be measured after harvest. The discarded produce that remains on the farm and is not managed as animal feed, by-products or food waste (i.e., sent to a managing entity with a waste license) shall be recorded as food loss. This information should be gathered through direct interviews/questionnaires with the farmer.

All the vegetables collected in the sampling area shall be classified into the food loss categories previously defined (see 4.2.5) and weighed. It is recommended to sort each type of vegetables into containers destined for each food loss category.

The entire vegetable shall be measured, both edible and non-edible parts. Additionally, after this measurement, an average of the proportion of the edible and non-edible parts may be calculated by separating the non-edible parts. The obtained sample results shall be registered.

4.3.2.1.2 Multiple-harvest and multiple-cut vegetables

In the case of crops with multiple harvests or cuts (or even continual cuts), a minimum of 3 measurements should be conducted to assess harvest loss: one after the 1st cut, another one after the middle cut and the last one after the last cut. The intermediate cuts losses not being directly measured should be obtained by calculating the average between the 3 measurements conducted. The total harvest food loss shall then be summed as follows:

$$\text{Harvest FL} = 1^{\text{st}}\ \text{cut FL} + 2^{\text{nd}}\ \text{cut FL} + 3^{\text{rd}}\ \text{cut FL} + 4^{\text{th}}\ \text{cut FL}\ldots + \text{Final cut FL}$$

The total yield of the sampled plot is needed to calculate the Food Loss percentage (see 4.4.1). If this is not available, it shall be obtained as the average between the known cuts, i.e., the unknown cut yields shall be calculated as the average of the known ones (see Annex A1). The total harvested shall be obtained as the sum of all the cuts yields:

$$\text{Total harvested} = 1^{\text{st}}\ \text{cut} + 2^{\text{nd}}\ \text{cut} + 3^{\text{rd}}\ \text{cut} + 4^{\text{th}}\ \text{cut}\ldots + \text{Final cut}$$

In case that pre-harvest and/or post-harvest food loss are measured, the same requirements as in a single-cut crop (4.3.2.1.1) apply.

Food eventually lost in the farm premises and not managed as animal feed, by-product or food waste shall also be counted as food loss.

The obtained sample results shall be registered.

4.3.2.1.3 Fruits

The measurement of fruit food loss follows the same steps as in vegetables. It is recommended to define the sampling area by using the number of trees. In this case, the chosen trees should be tagged visibly, and a zone of influence of each tree should be established with a circle around it, which corresponds to the projection of the canopy on the ground.

Where trees are disposed in rows with slopes, the area of influence should be adjusted to the mid-point of the inter-row zone. In each row, the limits of each tree's influence area should also be marked between the bases of the trees.

Measurements shall be made as follows:

- Pre-harvest losses shall be measured 1 to3 days before harvesting. Only the fruits on the ground shall be collected in this stage.

- Harvest losses shall be measured within 3 days from the moment of harvest, avoiding any interference with harvesting operations. All the remaining fruits on the ground in the sampling areas shall be collected. The fruits on the trees shall be collected in case it is the last harvest of the year and subject to the farmer's permission -otherwise a visual estimation can be made.

All the collected fruits shall be classified into the defined categories -preferably sorted in separate containers- and weighed. The obtained sample results shall be registered.

Food eventually lost in the farm premises and not managed as animal feed, by-product or food waste shall also be counted as food loss.

4.3.2.1.4 Roots and tubers

Quantification of food loss in roots and tubers shall be assessed through on-site measurement after harvest. This measurement shall be conducted within 3 days from the moment of harvest, avoiding any interference with harvesting operations, within the predetermined sample. All the remaining roots and tubers on the ground shall be collected, and it is also recommended to collect those under ground level to a minimum depth of 15 cm.

All the products collected in the sampling area shall be classified into the food loss categories previously defined (see 4.2.5), roughly cleaned to remove adhering soil and weighed. It is recommended to sort each type of root and tuber into containers destined for each food loss category.

The obtained sample results shall be registered.

4.3.2.1.5 Cereals and pulses

Food losses in cereals and pulses may be quantified through direct or indirect measurement.

Direct measurement should be conducted within 3 days from the moment of harvest, avoiding any interference with harvesting operations, although this period may be extended if necessary, since these products are less perishable than other food commodities considered. The number of grains/kernels on the ground or not harvested shall be counted. Samples should be taken in phenological homogenous areas and shall be georeferenced using GPS. All the collected grains/kernels shall be weighed.

Alternatively, food loss may be indirectly quantified through the assessment of the difference between the attainable and the real yield. In this case, a representative subsample of individual plants shall be collected manually at physiological maturity before harvest, and then the individual yield components shall be assessed (divided into spikes, spikelets, grains, and test mass) to compute an attainable cereal yield [18].

At harvest, when the combine passes, the real yield, which is the total amount harvested by the combine, shall be obtained.

The mathematical difference between the attainable and real yield shall be calculated to obtain harvest losses (i.e., food loss at the primary production stage).

The results shall be registered.

4.3.2.2 Sensor-based quantification

Sensor-based quantification may be performed through semi-automated or automated approach (see 4.2.4). In both cases, data collection shall be conducted as follows [20]:

- <u>Platform</u>: cameras may be mounted on tractors or on drones (UAVs), depending on the needs and the capacity of the organization.

- Sampling strategy: the user may choose to register only a certain percentage of the total field or to map the entire field. Tractor or robot-based systems typically only see a section of the field (separate samples), but drones can also be programmed to do so, for instance, through waypoint flights.

Most UAV systems typically assess the entire field to create an orthomosaic with Structure-from-Motion (SfM) software. The orthomosaic maps usually have a very homogeneous field of view, which facilitates data analysis and interpretation. It also enables full coverage of the entire field, resulting in the most reliable loss estimates (see Figure 2).

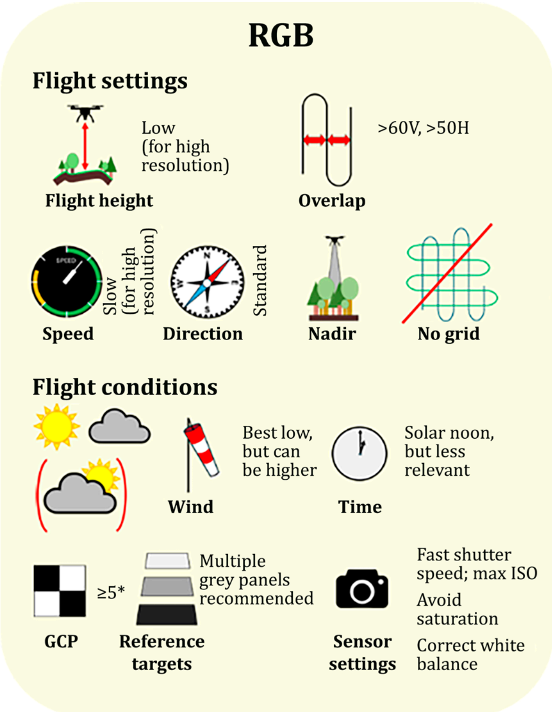

Figure 2 — General guidelines for collecting UAV data for sampling the entire field [20]

The processing of the data differs between the semi-automated and automated approaches. The requirements for both processes are specified below:

a) Deep learning (AI) technology to assess pre-harvest and harvest losses (e.g. food loss measurement in cauliflower crops).

- Data collection: high-resolution RGB (Red-Green-Blue) data collection, should be collected with a low-flying RGB UAV. Flight speed and altitude should be adjusted to ensure image clarity (approximately 12 m height) [20]. Data can be collected as videos, although it is recommended to take individual imagery. Imagery should be collected at least after the harvest to assess absolute food loss. It is recommended to also collect data prior to harvest, to obtain total yield and be able to calculate relative food losses. Imagery from a range of fields (at least five different fields) shall be collected to build a robust model.

- Data preprocessing: the imagery should be processed to retrieve georeferenced orthomosaics using SfM (Structure from Motion) software. As an alternative, individual images may be used.

- Data labelling: for creating a training dataset, representative areas within a field shall be collected. Within these areas, all the plants in the selected area shall be labelled with one or several items of product (units, edible/non-edible…). Data augmentation techniques (geometric transformations, colour and contrast adjustments, noise injection, augmentation through generative models) are recommended, in particular when the training datasets are relatively homogeneous.

- Neural network training: supervised networks shall be trained through machine learning frameworks (e.g., Tensorflow or Pytorch), consisting of:

  — Image analysis through computer vision and deep learning algorithms,

  — Metrics extraction module of one image or the whole field,

  — Computed metrics format for end-user needs.

- Model evaluation: testing the robustness of the method shall be done on at least one separate, independent dataset (i.e., a dataset that was not used for training or validating the model). Comparisons with ground-truth measurements should be performed.

- Food loss data for the analysed plot shall be calculated.

- A report shall be prepared including the resulting food loss data in the analysed plot, along with achieved coverage (% of plot/farm/site), a brief data quality statement (e.g., resolution, occlusion risk, weather) and key constraints encountered.

b) UAV-based high-resolution RGB to assess harvest losses (e.g. food loss measurement in apples crops)

- Data collection: focused and high-resolution images shall be acquired by conducting UAV flights at low altitude. Flights should be performed at a speed and height that ensure image clarity (approximately 12 m height), with an industrial multirotor UAV equipped with a ≥ 40 MP full-frame optical sensor equipped with a 55 mm focal length lens, and with viewing angles (oblique view) at nadir, 50º, and 70º.

- For creating a training dataset, flights should be performed in a sufficiently large number of fields, with a sufficient variety of the orchard. Where feasible, a ground truth dataset should be collected to quantify and correct for the percentage of fruit not observable due to the canopy structure.

- The precise location of each tree shall be measured with an RTK GNSS (Real-Time Kinematic Global Navigation Satellite System).

- Data preprocessing: Collected imagery shall be prepared for annotation, through:

  — Selection of relevant subregions of the orchard canopy to gain efficiency,

  — Creation of Python scripts to cut the relevant region from the raw image, save the chunk and the coordinates of the selected region in a file,

  — Application of data augmentation techniques to improve data collection.

- Data labelling: Data shall be annotated by labelling all the identified apples using the following categories:

  — Good apples (edible and marketable),

  — Fallen apples (edible but not marketable),

  — Damaged apples (non-edible and not marketable).

This labelling may be improved by adding a category of "uncertain image" in each one, for those images without a clear definition.

- Neural network training: deep learning architectures shall be developed through machine learning frameworks (e.g., 'YOLO', Faster R-CNN (Region-based Convolutional Neural Network) to detect damaged apples in higher-resolution RGB UAV images.

- Model evaluation: model evaluation shall also be done on an independent test dataset. Comparisons with ground-truth measurements should be performed to determine a canopy shielding correction factor.

- Food loss data for the analysed plot shall be calculated.

- A report shall be prepared including the resulting food loss data in the analysed plot, along with achieved coverage (% of plot/farm/site), a brief data quality statement (e.g., resolution, occlusion risk, weather) and key constraints encountered.

4.3.3 Meat and dairy

The quantification of meat and dairy food loss shall be conducted within the period specified in subclause 4.1, regardless of the specific site where losses occur.

In the case of meat all the animals dead or culled during that period shall be weighed and counted as food loss, irrespective of the intended destination of the animal or the causes of the death (e.g., health issues, absence of market, overproduction, etc.). The following cases shall be included:

- Pre-slaughter losses: on-farm animal mortality due to disease, injury, or poor management in animals already considered ready to be slaughtered;

- Handling and transport losses: spoilage, bruising, or damage during transportation to slaughterhouses;

- Slaughter-related losses: rejection of carcasses or parts due to contamination, disease, or regulatory standards.

The actual mass of the dead animal shall be registered, including both edible and non-edible parts.

In the case of milk, all the losses within the specified period shall be measured. The following cases shall be included:

- Production losses (milking losses): on-farm milk discarded due to mastitis, antibiotic contamination, or improper milking techniques;

- Storage and handling losses (post-milking losses): spillage or spoilage from poor storage, cooling failures, or transport inefficiencies;

- Processing rejection: milk rejected at processing plants due to quality non-compliance (e.g., high bacterial load, contamination).

Meat and dairy food loss data shall be registered. It is recommended to also register the site where losses occur (e.g., the farm, the transport, intermediate facilities, etc.), as along with its final destination (e.g., incineration, landfill, etc.). Meat and dairy destined for by-products or animal feed shall not be counted as food loss.

4.3.4 Aquaculture

4.3.4.1 Fish

The quantification of food loss for fish shall be conducted from the moment the fish reaches the marketable size (normally at growth phase in sea) to the moment when the fish is slaughtered, including transport (See figure 3 below that shows the stages for an Atlantic salmon traditional production cycle with open sea cages. Food loss occurs within Phase 4, Growth phase at sea). During these stages, losses may be counted on a daily basis mechanically and/or manually.

Dead fish from the bottom of the fish pen should be pumped to the surface mechanically, whereby there should be a routine of registering the number of fishes lost. Sick or dead fish that float on the surface of the fish cage should be counted manually when they are removed with a net. During delousing procedures where fish are removed from pens, fish counts shall also be recorded.

This information shall be recorded and can be stored locally or through commercial databases. Additional parameters, such as biomass, temperature, and oxygen levels, may be collected, according to the technological platform standardisation criteria.

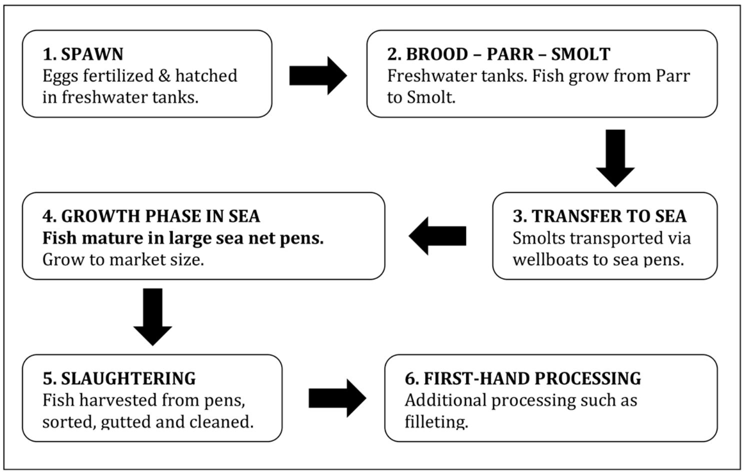

Figure 3 — The Atlantic salmon production cycle

4.3.4.2 Molluscs

The quantification of food loss in molluscs' cultivation shall be conducted a minimum of one time in the sample specified in subclause 4.2.4. It is recommended to additionally assess food loss after an eventual cleaning process.

At least 3 mesh sleeves of equal length (e.g., 1 metre) shall be sampled from each of the 3 selected areas. The extraction points shall be identified and georeferenced.

Each sleeve shall be analysed to quantify the total number and mass of both dead and alive specimens. It is recommended to additionally analyse individual marketable parameters of the live specimens and the presence of predators.

In case that molluscs undergo a cleaning process, the whole sleeve should be weighed before and after the automatic cleaning procedure. The cleaned and sellable product should be analysed as in the previous case, and the number of molluscs damaged and discarded should be registered as food loss.

Food loss per sleeve shall be registered, including both edible and non-edible parts of molluscs.

It is recommended to collect additional data on variables such as water parameters, planktonic blooms, and weather conditions during molluscs farming.

4.4 Data extrapolation

4.4.1 General

Food loss data collected through sample measurement shall be processed to estimate total food loss in the selected plot(s), farm(s), or site(s) (4.4.1) and, where applicable, to extrapolate these estimates to a wider territory (4.4.2).

4.4.2 Extrapolation of on-site data to the total plot, farm or site

4.4.2.1 Agriculture

For all the crops, the total food loss of the plot shall be obtained as the sum of (applicable) pre-harvest, harvest, and post-harvest losses:

$$\text{Total FL} = \text{Pre harvest FL} + \text{Harvest FL} + \text{Post harvest FL}$$

The following steps shall be taken to extrapolate the loss data from the sampled area to the total cultivable area of the plot:

Step 1:

Calculate the total sampled area in hectares by multiplying the number of random samples taken by the average size of the sample.

E.g., 10 sample frames of 1 row of 15 m in length with a width of 2 m.
Sample = 1 m × 15 m × 2 m = 30 m^2
Total sample area = 10 × 30 m^2 = 300 m^2 = 0,03 ha

This calculation is not required if the sample is the number of trees.

Step 2:

Calculate the total cultivable area of the plot in hectares, through the following methods:

a) Information provided by the farmers.

b) In case of regular plots, calculating the total number of rows, their length, and width.

E.g. 50 rows with a length of 120 m and a row width of 2 m.
Total cultivable area = 50 × 120 m × 2 m = 12 000 m^2 = 1,2 ha

c) In case of irregular plots, using Geographic Information Systems and digital applications that allow for the calculation of plot layouts through satellite imagery.

When using the number of trees in the plot, options a) and c) should be applied for irregular crops, and option b) for completely regular crops.

It shall be established the percentage of the sampled area (or sampled trees) within the total cultivable area (or number of trees) of the plot.

E.g. A sample of 0,03 ha in a plot of 1,2 ha.
% sampled area to the total cultivable area = $\frac{0{,}03\,\text{ha}}{1{,}2\,\text{ha}} \times 100 = 2{,}5\ \%$

Step 3:

Convert food loss mass from the sampled area into kilograms per square metre in each sample. The following parameters shall then be analysed for the entire data set:

a) Number of samples

b) Maximum value

c) Minimum value

d) Arithmetic mean

e) Median

f) Standard deviation

g) Standard error or confidence interval (at least one)

> E.g., sample row of 15 m in length and width of 2 m, and 7 kg food loss.
>
> $$\text{FL m}^2 = \frac{7\,\text{kg}}{1{,}5\,\text{m} \times 2\,\text{m}} = 0{,}23\ \text{kg/m}^2$$

It should be determined whether to use the median or arithmetic mean as the most representative value to estimate losses in the plot, depending on whether the difference between both parameters is significant or not. Standard deviation shall be calculated, and the standard error or confidence interval may be included.

Step 4:

The same operation should be performed for each of the food loss categories previously defined (see 4.2.5).

Table 9 — Presentation of results for the analysis of losses in a plot

Farm ID	27_County_9					
Plot ID	27_County_9_A					
Location	County 9. Region X					
Crop(s)	Tomatoes					
Sample ID	**Sample size (m^2)**	**Total food losses (kg)**	**Food losses (kg/m^2)**	**Marketable (kg/m^2)**	**Edible (kg/m^2)**	**Non-edible (kg/m^2)**
1	30	7	0,23	0,12	0,08	0,03
2	30	31	1,02	0,25	0,32	0,45
3	30	15	0,5	0,01	0,17	0,32
4	30	8	0,25	0	0,14	0,11
5	30	15	0,5	0,17	0,12	0,21
6	30	7	0,24	0,02	0,09	0,13

7	30	4	0,14	0	0	0,14
8	30	5	0,17	0,03	0,05	0,09
9	30	15	0,5	0,14	0,12	0,24
10	30	17	0,57	0,08	0,17	0,32
Min		4	0,14	0	0	0,03
Max		31	1,02	0,25	0,32	0,45
Mean		12	0,412	0,082	0,126	0,204
Median		11	0,375	0,055	0,12	0,175
Std dev		8	0,266	0,086	0,086	0,129
Std. error		±2,53	±0,084	±0,027	±0,027	±0,041

NOTE 1 In this and the following tables, “marketable” refers to produce that is edible and marketable; “edible” refers to produce that is edible but not marketable; and “non-edible” refers to produce that is not edible and not marketable (see 4.2.5).

Step 5:

The parameters obtained shall be converted into kilograms or tonnes per hectare (kg/ha or t/ha) and then losses shall be extrapolated to the total area of the plot.

E.g. sample row of 15 m in length and width of 2 m, and 7 kg food loss.

Total FL = 12 000 m^2 × 0,412 kg/ha = 4 944 kg = 4,9 t

$$FL_{ha} = \frac{4{,}9\ \text{t}}{1{,}2\ \text{ha}} = 4{,}12\ \text{t/ha}$$

Table 10 — Extrapolation of the obtained results to the total area of the plot

Farm ID	27_County_9				
Plot ID	27_County_9_A				
Location	County 9. Region X				
Crop(s)	Tomatoes				
Total sample size (ha)	**Plot size (ha)**	**Food losses (t/ha)**	**Marketable (t/ha)**	**Edible (t/ha)**	**Non-edible (t/ha)**
0,03	1,2	4,12	0,82	1,26	2,04

In the case of trees, the number of trees per hectare shall be first calculated and then the average food loss per tree shall be multiplied by the number of trees per hectare. The rest of parameters of Table 10 shall be calculated following the same process.

E.g. A sample of 13,5 kg of FL per tree in a plot of 110 trees (0,17 ha).

$$FL_{ha} = \left(\frac{110\,\text{trees}}{0{,}17\,\text{ha}}\right) \times 13{,}5\ \text{kg} = 8{,}7\ \text{t/ha}$$

Step 6:

Additional food loss indicators should be calculated as follows.

a) Food Loss to total production (%): the percentage of food losses in relation to the Total harvest produced (including food loss)[2]:

$$\text{FL total production (\%)} = \frac{\text{FL}}{\text{Total harvested} + \text{FL}} \times 100$$

E.g. A sample of 0,72 kg of FL with a total harvest of 13,62 kg (including FL)

$$\text{FL total production (\%)} = \frac{0{,}72}{12{,}9 + 0{,}72} \times 100 = 5{,}28\ \%$$

b) Food Loss to harvest: the percentage of food losses in relation to the Total harvested (excluding FL):

$$\text{FL harvest (\%)} = \frac{\text{FL}}{\text{Total harvested}} \times 100$$

E.g. A sample of 4,12 kg of FL with a total harvest of 65 kg (excluding FL)

$$\text{FL harvest (\%)} = \frac{4{,}12}{65} \times 100 = 634\ \%$$

The same calculations should be made for each food loss category in both indicators.

4.4.2.2 Meat and dairy

The totality of meat and dairy losses in a farm shall be measured, and on-site sampling does not apply. All these losses shall then be aggregated by farm.

4.4.2.3 Fish

The totality of fish losses shall be measured, and on-site sampling does not apply. It is recommended to transmit and store food loss information in purpose-specific databases, along with other information, such as the associated causes of food loss. Automatically aggregated data can be used to generate insights across the industry.

All losses from the ready for slaughter moment (e.g. normally above 3 kg size in salmon aquaculture), until the moment the fish is slaughtered, shall be considered as food loss. This may include part of the grow-out stage at sea, the catch, and transport. All these losses shall then be aggregated by farm.

[2] Within this document, total production is defined as the sum of harvested output and quantified food losses. This approach is based on the premise that these combined quantities provide the most accurate representation of the total amount of product that reached the ready-to-be-harvested stage, irrespective of whether it was ultimately harvested.

4.4.2.4 Molluscs

Food loss in a molluscs farm shall be calculated by multiplying the average mass of sleeves by the obtained percentages of losses, materials waste, and live molluscs. These figures shall be converted into total mass based on the total number of sleeves.

Total FL = Harvest FL + Post harvest FL

$$\text{FL} = \text{Socks average mass} \times \text{Total nr. sleeves} \times \frac{\text{FL}}{\text{Total harvested} + \text{FL}}$$

E.g. A mussel farm with 16 800 sleeves, average mass of 50 kg and 5 % of losses $\text{Total FL} = 50 \times 16\,800 \times \frac{2{,}5}{47{,}4 + 2{,}5} = 42\,000\ \text{kg}$

4.4.3 Extrapolation of the calculated figures per plot, farm or site to the entire territory

For studies intended to quantify food loss within a specific territory, a sample of plots, farms or sites representative of a given economic activity (same NACE code and CPA category) within a territory shall be selected, and the basis for this selection and data extrapolation shall be documented (see Annex B). When applicable, monitoring systems should be established to ensure feasible, reliable and accurate data over time, ensuring producer participation and data representativeness.

Based on food loss data gathered on each plot according to the above criteria, the following parameters shall be calculated and presented as shown in Table 11:

a) Number of samples,

b) Maximum value,

c) Minimum value,

d) Arithmetic mean,

e) Median,

f) Standard deviation,

g) Standard error or confidence interval (at least one).

A random or stratified approach may also be used to select plots and extrapolate data, depending on known drivers such as variety, harvest method, or farm size. In that case, food loss estimates should be weighed by the selected driver when aggregating food loss data across plots [5]. Standard deviation shall be calculated, and the standard error or confidence interval may be included.

Table 11 — Presentation of the results obtained for all quantified plots on-site — Example of tomato cultivation (CPA 01.13.34) in Region X

NACE Class	01.13 Growing of vegetables and melons, roots and tubers
CPA Code	01.13.3 Other fruit-bearing vegetables / 01.13.34 Tomatoes
Crop(s)	Tomatoes
Territory	Region X
Type	Sample measured

ID	Total sample size (ha)	Plot size (ha)	Food losses (t/ha)	Marketable (t/ha)	Edible (t/ha)	Non-edible (t/ha)
27_County_9_A	0,03	1,2	4,12	0,82	1,26	2,04
27_County_9_B	0,03	2,5	6,57	0,97	2,2	3,4
12_County_9_A	0,06	3,9	2,12	0,01	0,9	1,21
12_County_9_B	0,05	1,8	5,82	1,12	1,92	2,78
12_County_9_C	0,02	0,9	3,46	0,54	0,97	1,95
4_County_1_A	0,06	4,2	3,64	0,65	1,12	1,87
5_County_1_A	0,13	7,3	4,57	0,34	1,78	2,45
6_County_1_A	0,07	3,3	4,77	1,67	1,12	1,98
9_County_4_A	0,05	2,9	5,06	1,29	0,65	3,12
9_County_4_B	0,08	4,1	4,31	0,21	0,88	3,22
Min			2,12	0,01	0,65	1,21
Max			6,57	1,67	2,20	3,40
Mean			4,44	0,76	1,28	2,40
Median			4,44	0,74	1,12	2,25
Std dev			1,25	0,52	0,51	0,71
Std. error			±0,395	±0,164	±0,161	±0,224

To calculate relative food loss in animal farms and aquaculture, the herd or stock size of the sample and the farm (kg, t) shall be used instead of the cultivated area (ha) (see Annex B paragraph d.).

4.4.4 Estimation of losses for a specific economic activity across the territory

In agriculture crops, the total food loss of the studied economic activity within a territory shall be calculated by multiplying the total cultivated hectares by the average food loss. The total cultivated hectares should be obtained from official sources. If not available, it should be estimated by multiplying the number of registered farms by the approximate average size or by using other representative data. The sources and statistical limitations of this data should be documented, and its uncertainty should be considered when extrapolating resulting food loss.

The average food loss of the sampled plots may be expressed by the mean or the median (in case of significant disparities between these two parameters).

E.g. Total tomato losses in Region X: FL_{ha} = 4,44 t/ha Total tomato cultivation area = 230 ha Total tomato FL = 4,44 t/ha × 230 ha = 1 022 t

Table 12 — Presentation of the results obtained for the estimation of losses in a specific economic activity — Example of tomato cultivation (CPA 01.13.34) in Region X

NACE Class	01.13 Growing of vegetables and melons, roots and tubers		
CPA Code	01.13.3 Other fruit-bearing vegetables / 01.13.34 Tomatoes		
Crop(s)	Tomatoes		
Territory	Region X		
Type	Estimated total territory		
Total food losses (t)	**Marketable (t)**	**Edible (t)**	**Non-edible (t)**
1 022	175	295	552

The same calculation shall be performed for each analysed commodity group. For animal farms and aquaculture, the herd or stock size of the sample and of the farm (kg, t) shall be used instead of the cultivated area (ha).

Annex A
(informative)

Examples of use of the methodology

A.1 Food loss quantification in tomato crops

A.1.1 General

The food loss quantification methodology is applied in this case study of a tomato plot in Spain[3].

A.1.2 Measurement planning

According to the methodology, a measurement plan was prepared, containing all the necessary information defined at the planning stage: the scope definition, perceptual data of the plot, the sampling strategy and the predetermined food loss categories.

The scope was defined as "the study of food losses in tomato crops in a plot". The relevant information for the measurement was collected through a personal interview with the farmer (Table A.1). The objectives of this interview were to gather the necessary data to define the plot, to understand the context of the activity and to obtain perceptual quantitative data of food loss and its causes from the farmer perspective. In this case, this interview included an onsite visit to the plot.

As a sample strategy, 3 rows of 7 m were selected, representing 21 m^2, which is approximately 1 % of the total plot (0,215 ha), regarded as a sufficient sample.

E.g. Sample of 3 rows of 7 m, representing 21 m^2
% sampled area to the total cultivable area = $\frac{0,0021\,\text{ha}}{0,215\,\text{ha}} \times 100 = 0,98\%$
Total sample area = 3 × 7 m × 1 m = 21 m^2

Table A.1 — Example of questionnaire to collect information from agriculture through perceptual approach

<table>
<tr><th colspan="3">Basic data of the plot</th></tr>
<tr><td colspan="2">Name of the interviewee:
Isabel García</td><td>Position of the interviewee:
Owner of the farm and farmer</td></tr>
<tr><td>Farm ID</td><td colspan="2">27_County_9</td></tr>
<tr><td>Plot ID</td><td colspan="2">27_County_9_A</td></tr>
<tr><td>Location</td><td colspan="2">County 9. Region X</td></tr>
<tr><td>Crop(s)</td><td colspan="2">Tomatoes</td></tr>
<tr><td colspan="3">Area/surface of the analysed parcel (ha): 0,215</td></tr>
<tr><td>Type of soil:</td><td colspan="2">Clayish</td></tr>
<tr><td colspan="2">Seed variety: Solanum lycopersicum</td><td>Cultivated variety: Roma</td></tr>
</table>

[3] Additional information on the case studies is available in the *Food Loss Quantification Manual* [5].

Plant spacing	70 cm
Rows number: 21	**Rows spacing:** 1 metre
Method of irrigation	Drip irrigation
Main characteristics of this year's production	
Average yield in the plot (tonnes/ha): 85	**Estimated yield for this year. (tonnes/ha):** 60
Main reasons for the differences between average and estimated production: the drought in recent years will significantly reduce tomato production.	
Marketable production of the estimated yield: 75%	**Main parameters to be considered as marketable"** (size, shape, appearance quality, etc): Size and colour. Marketable tomatoes have a length of 5–8 cm and a diameter of 3–4 cm. Regarding color, tomatoes with more than 10% of their surface exhibiting green or yellow areas are considered non-marketable
Of the marketable production, what proportion will be considered as the first category? What will be the difference in remuneration compared to the other categories? Approximately 80% will be in the first category. Then, there will be 15 % in the second category, with a 60 % decrease in remuneration, and the remaining 5 % will be for industrial use with no remuneration.	
Have these parameters been similar or more demanding in the last 10 years? Why? The level of demands has been increasing over the last years, especially regarding the colour, as the market does not accept tomatoes with a very red hue as it considers them excessively ripe	
Main characteristics of the harvesting process	
Brief description of the harvesting process: Approximately five harvests are conducted, usually one per week. The tomatoes are hand-picked, detaching the fruit from the plant by applying pressure with the thumb on the calyx. Hired personnel employed by the farm owner are involved in the harvesting process. The fruits are packed in single-layer crates, preserving the calyx along with part of the stem. For plant sanitation purposes, any fruits that have fallen to the ground or are discarded during the harvest for any reason are removed from the cultivation area. The tomatoes are then transferred from the harvest containers to larger containers known as "field bins", which are large wooden or plastic crates. These field bins are loaded onto a truck for transportation to the sorting and packing facility.	
How many months does the harvest season for this crop last? 3 (June-August)	
Number of estimated cuts per agricultural campaign: 5	
In terms of production and discards, would these cuts be of equal volume? (Yes/No): No	
Which cuts would have the highest production level and what proportion would the rest have in relation to them? The first one. The others are: 2nd cut: (60 % of production from first cut) / 3rd: 45 % / 4th: 40 % and 5th: 40 %.	
Estimated harvest calendar: 1st cut: 4th July / 2nd cut: 11th July / 3rd cut: 18th July / 4th cut: 25th July and 5th cut: 1st August	

<table>
<tr><th colspan="2">Estimated harvest schedule:</th></tr>
<tr><td colspan="2">What amount of the total production will be discarded from when a product is mature enough to be harvested until it has been harvested?
— Kilos/ha:
— Tonnes/ha: 17
— % from total production: 20 %</td></tr>
<tr><td colspan="2">Main reasons (see reasons): C2 and B1</td></tr>
<tr><td colspan="2"></td></tr>
<tr><th colspan="2">Reasons:</th></tr>
<tr><td>A. Behavioural
1) Insufficient understanding of market fluctuations and price mechanisms.
2) Lack of knowledge of harvest/post-harvest technologies and methods
3) Lack of training
4) Lack of investment capacity
5) Inappropriate choice of product varieties
6) Inadequate or improper handling of the product
7) Wrong collecting time
8) Lack of knowledge of fiscal aid tools and bureaucracy
9) Excess of production to ensure fulfilment of contracts
10) Lack of trust in central administration/institutions
11) Inappropriate planting/breeding scale
12) Interpersonal dynamics altering the supply chain efficiency
13) Bycatch</td><td>B. Societal
1) Low market price of food products
2) Low market power of farmers due to unfair contracts and competition
3) Marketing and industry standards
4) Food safety regulations and standards
5) Lack of coordination and communication among actors and territories
6) Lack of adequate supply chain capacity
7) Inefficient storage and processing infrastructure
8) Inefficient transportation infrastructure
9) Direct subsidies on production
10) Market organization
11) Marketing strategies
12) Lack of efficiency of equipment
13) Adoption of a paradigm that produce losses and waste
14) Missed application of technological advances
15) Inability to cope with unexpected external changes
16) Lack of skilled labour availability</td></tr>
<tr><td colspan="2">C. Environmental
1) Unexpected climate and weather events
2) Pests, diseases and phytosanitary issues
3) Consumption or damage by insects, rodents, birds or microbes (e.g. Mold, bacteria), or predators
4) Natural weather/meteorological conditions
5) Old plantations
6) Soil deterioration</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Additional aspects	
What percentage, if any, of the product produced in the plot has been donated to social entities (gleaning, food banks, charitable organizations, Red Cross, or others)?	— % from total production: 2,5 % — Kilos: — Tonnes: 0,300
Do you have any recommendations for marking the sampling areas to avoid interfering with harvesting activities (such as using measuring tapes to zone the area, marking with stakes, or using ribbons on trees, etc.)? Yes, by using only stakes, which would not hinder the harvesting process.	
Other issues not mentioned that you would like to highlight:	

A.1.3 Food loss quantification

The harvest season of tomatoes include several cuts depending on the conditions of tomatoes, the weather, the demand and other factors expressed by the farmers. In this case, the tomato crop was subject to 5 cuts, and 3 measurements were conducted, according to the methodology: one after the 1st cut, another one after the middle cut and the last one after the last cut (Figure A.1).

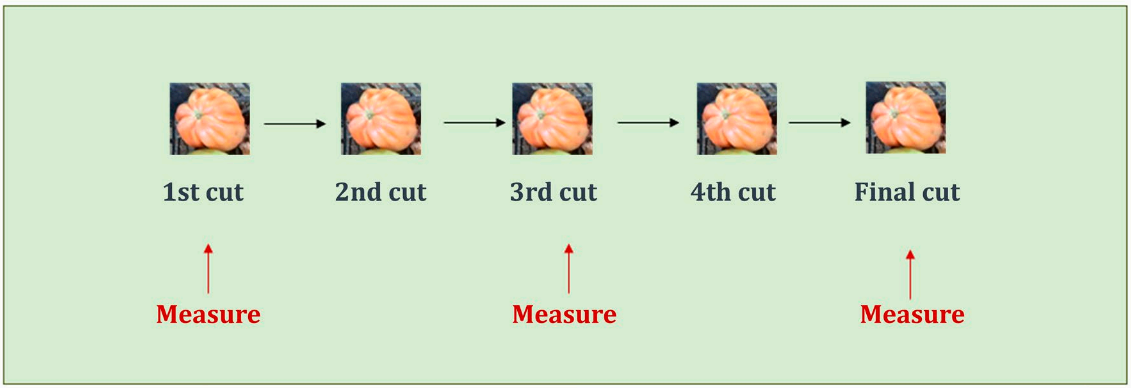

Figure A.1 — Tomato measurements in a harvest of 5 cuts

The average of the first and the 3rd cut, considered intermediate cuts, was applied to the 2nd and the 4th cuts. These amounts were added to the losses calculated for the final harvest, which cannot be extrapolated to the rest for several reasons.

After the first cut, 1,37 kg of lost tomatoes were collected and measured. After the second cut, 0,83 kg, and after the final cut, 2,34 kg were measured. The second and the fourth cut were assigned the average food loss of the first and the third cuts (1,10 kg), resulting in a total measured food loss of 6,74 kg.

These measurements were then converted into tonnes per hectare to extrapolate them to the total area of the plot:

$$FL/m^2 = \frac{6{,}74\ \text{kg}}{21\ \text{m}^2} = 0{,}32\ \text{kg/m}^2$$

$$\text{Total FL} = 2\ 150\ \text{m}^2 \times 0{,}32 = 690\ \text{kg} = 0{,}69\ \text{t}$$

$$FL_{ha} = \frac{0{,}69\ \text{t}}{0{,}215\ \text{ha}} = 3{,}21\ \text{t/ha}$$

The results were extrapolated to total plot for each cut, as depicted in Figure A.2.

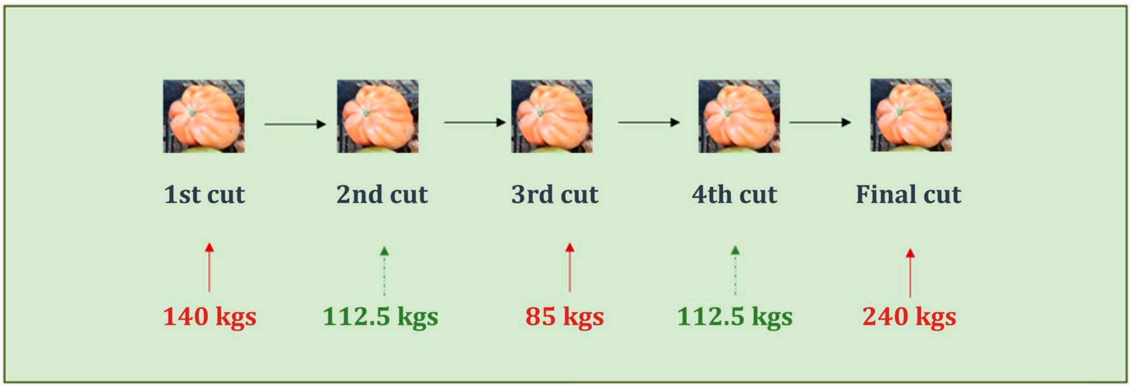

Figure A.2 — Data obtained through on-site measurement (in red) and estimated data (in green)

The following results were obtained:

$$\text{Total FL} = 140 + 112{,}5 + 85 + 112{,}5 + 240 = 690\ \text{kg}$$

The Food Loss total production (%) was calculated by dividing Total food loss by Total harvest (including FL).

$$\text{FL total production (\%)} = \frac{\text{FL}}{\text{Total harvested} + \text{FL}} \times 100$$

In this case, the 2nd and the 4th cut yields were unknown, so they were estimated in the same way as food loss, i.e. the average of cuts 1 and 3.

— 1st cut = 2,3 tonnes,

— 3rd cut = 1,8 tonnes,

— Final cut = 4,7 tonnes.

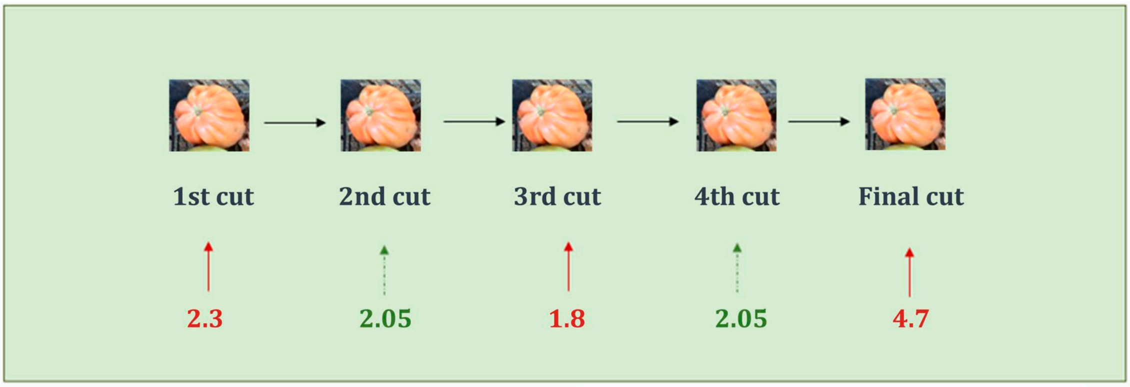

Figure A.3 — Data obtained through on-site measurement (in red) and estimated data (in green)

The following results were obtained:

Total Harvest = 2,3 + 2,05 + 1,8 + 2,05 + 4,7 = 12,9 tonnes

Though not being a definitive requirement of the methodology, pre-harvest and post-harvest losses were quantified in addition to harvest losses, in order to account for the total food losses of tomatoes during that season. Pre-harvest losses amounted to 25 kg and the post-harvest losses were 2 kg. Therefore, the total food losses for this tomato crop during that season amounted to 25 + 690 + 2 = 717 kg = 0,72 tonnes.

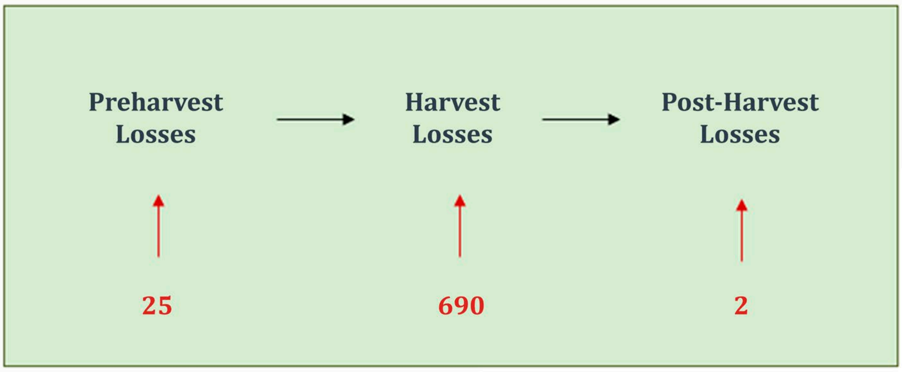

Figure A.4 — Total food losses in the tomato crop, according to key stages

With the data on total losses and total harvest, the Food Loss to total production (%) was calculated as follows:

$$\text{FL total production (\%)} = \frac{\text{FL}}{\text{Total harvested} + \text{FL}} \times 100$$

$$\text{FL total production (\%)} = \frac{0{,}72}{12{,}9 + 0{,}72} \times 100 = 5{,}28\ \%$$

Therefore, total losses represented 5,28 % of the total harvest -including food loss- at pre-harvest, harvest, and post-harvest stages, while 94,7 % constituted harvested and marketed food.

Food loss per hectare in the analysed plot amounted to 3,35 tonnes, as calculated below:

$$FL_{ha} = \frac{0{,}72\,\text{t}}{0{,}215\,\text{ha}} = 3{,}35\ \text{t/ha}$$

A.2 Roots and tubers

A.2.1 Description of the methodology developed for the case study

This case study integrated ground-based measurements with remote sensing to improve yield prediction and quantify harvest losses in potato production systems. Research was conducted in farmer-managed fields in Walhain, Belgium, focusing on Allegria and Jelly varieties, and in the experimental field of Bottelare.

The study followed the FOLOU Food Loss Quantification Manual, adopting its definitional framework without modification. Sampling involved excavating fifteen 1 m^2 plots per field and classifying tubers into four loss-related categories: undersized, oversized, unharvested marketable, and damaged. Fresh mass was used to calculate yield losses, with the focus limited to the harvest stage due to the impracticality of measuring pre-harvest losses.

To expand predictive power and spatial resolution, the methodology incorporated remote sensing, spatial heatmaps, and biostimulant and nitrogen treatments. These modifications were essential for adapting the methodology to larger, more diverse fields and preparing it for future scalability to other crops.

A.2.2 Results

The mechanical part of the analysis provided a large amount of information about how and where potato harvest losses happened in all the fields. The Allegria variety in Walhain yielded a total of 364,46 tonnes (58,78 t/ha), with mechanical losses of 14,7 tonnes (2,3 t/ha), which is 4,5 % of the total harvest. The total production of the Jelly variety was 305 225 tonnes (52,7 t/ha), and the losses were 8,36 tonnes (1,4 t/ha), which is 2,7 % of the total yield.

Strong intra-field variability was found; some plots had average or high yields, while others had very low or even no yields. These variations can be attributed to localised management techniques, minor topographic changes, field moisture, or micro-variations in soil texture.

The following important research questions about sampling strategy were addressed:

- To accurately estimate losses, how many plots are required?
- Which plot size offers the highest level of accuracy?
- What regional differences exist in spatial variability?
- Should loss consist of aboveground residues as well as belowground tubers?

To refine the methodology, different sampling configurations:

- 3×3 grid (1 m^2) preharvest
- 4×4 grid (1 m^2) harvest loss

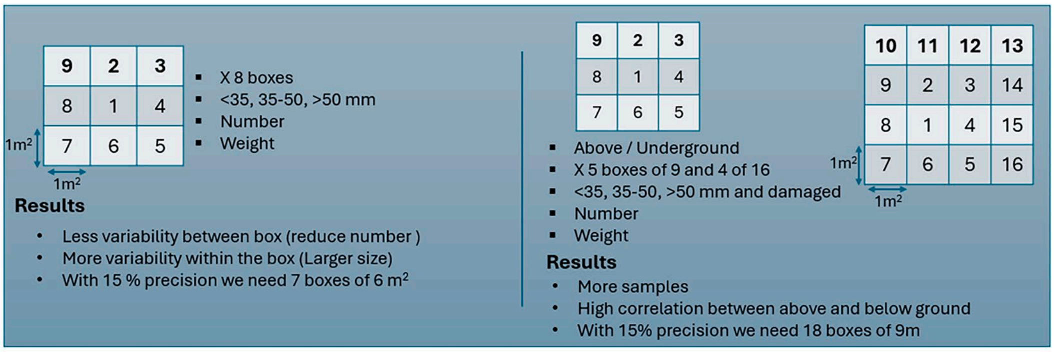

Figure A.5 — Optimal number and size of samples for pre-harvest (left) and harvest losses (right)

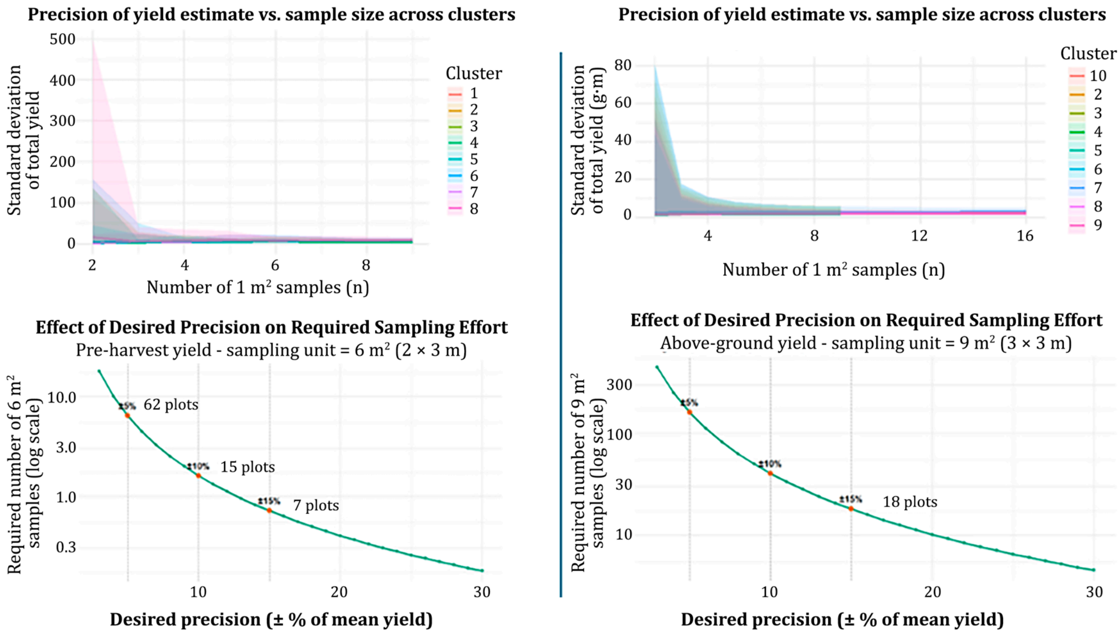

Figure A.6 — Comparison of yield estimate vs. sample size (in Melle)

The findings highlight that increasing the number of samples may help improve the precision of the results, though not in an automatic and proportional way.

A.2.3 Adaptability of the methodology to other food typologies

The core approach of the methodology is easily transferable to other similarly harvested crops, including bulb, root, and tuber crops, where size distribution and harvest efficiency strongly influence loss levels.

With appropriate adjustments to size classes and marketability criteria, the method can also be applied to leafy vegetables and fruit or vegetable crops. In these systems, losses can be categorized in similar ways, focusing on uncollected, damaged, or non-marketable produce. The study's complementary components -such as simple growth observations, field mapping, and evaluations of agronomic practices like irrigation or fertilisation- offer additional insights into the underlying causes of food loss.

A.2.4 Proposals to improve the current method

The methodology can be improved in two main ways: refining the core mechanical measurement of losses and enhancing the supplementary components that help explain why losses occur. For instance, placing sampling plots in problem-prone field zones or adjusting size or quality thresholds, among others, can increase representativeness.

A.3 Cereals and pulses

A.3.1 Description of the methodology developed for the case study

The FOLOU case study conducted by the Università Politecnica delle Marche (UNIVPM, Italy) focused on the assessment and quantification of food and production losses in cereal systems, specifically maize (*Zea mays*) and durum wheat (*Triticum turgidum subsp. durum*). These crops were selected due to their global relevance and contrasting agronomic characteristics. The study compared three agronomic management approaches -conventional, organic, and agroecological- with the overarching objective of validating the FOLOU Food Loss Quantification Manual under real farming conditions.

The case study followed the FOLOU Food Loss definitional framework without requiring any methodological adjustments, covering the period from when the cereal is ready to be harvested through to post-harvest stages.

Similarly, the quantification of losses followed both the FOLOU Food Loss Quantification Manual [5] and the guidelines of the FAO-recommended methodology [21], which are also incorporated into the manual itself. This methodology is based on the use of sampling frames to calculate cereal losses. Given the very high plant density of wheat (300–600 plants/m^2), smaller sampling quadrants of 1 m^2 were adopted instead of the larger frames proposed in the manual. In each one-hectare field, five quadrants were randomly positioned, georeferenced with GPS, and used to count grains on the ground before and after the passage of the harvesting machinery.

A key methodological advancement of this case study was its expanded perspective on losses. Rather than focusing solely on food losses occurring at harvest or post-harvest, the study incorporated production losses arising throughout the crop cycle. This broader approach captured the cumulative effects of biotic stresses (such as pests and diseases) and abiotic stresses (including drought, nutrient limitations, and climatic variability), which significantly affect yields long before harvest. By integrating these factors, the study moved beyond the conventional definition of food loss and provided a more comprehensive assessment of total yield reduction.

To conceptualize yield dynamics, the study applied the framework of real, attainable, and potential yields. Real yield refers to the actual yield obtained by farmers in a given year and field, strongly influenced by management practices and environmental variability. Attainable yield, approximated by average regional yield, represents a smoothed benchmark reflecting typical outcomes under prevailing conditions. Potential yield, defined as the theoretical maximum under zero-stress conditions, served as a reference to illustrate yield gaps. This framework enabled the identification of losses attributable to both seasonal stress factors and structural limitations in management practices.

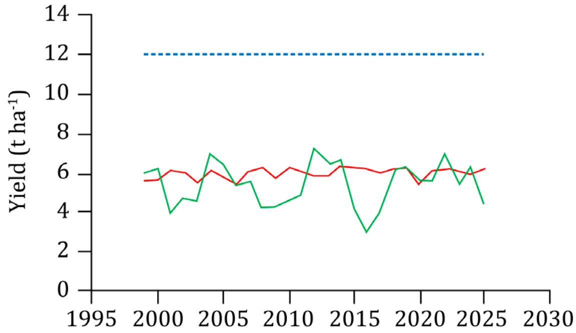

Figure A.7 — Real yield (green), average regional yield (red), and potential yield under zero-stress conditions (blue)

A.3.2 Results

The results demonstrated clear yield differences across management systems and crops, highlighting the relevance of the applied methodology. In wheat, conventional management achieved the highest average yield (7,75 t/ha), followed by agroecological management (5,87 t/ha), while organic management resulted in substantially lower yields (3,11 t/ha), as shown in Figure 2. Despite these differences, pre-harvest losses were negligible across all systems. Grain counts before harvesting revealed no losses, and post-harvest assessments identified only two to five grains per square meter on the ground (48 000 grains per hectare under conventional management and around 12 000 grains per hectare under agroecological management, while no grans were found in the organic field). Even in the worst-case scenario, this represented approximately 1% of total production, confirming that harvest-related food losses in wheat were minimal, as shown in Figure A.8.

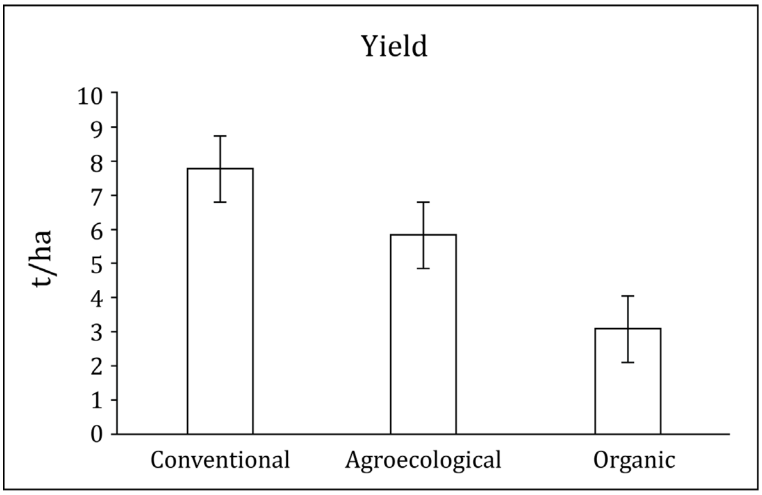

Figure A.8 — Wheat grain yield in the three management systems — Bars represent the standard error of the mean (N = 5)

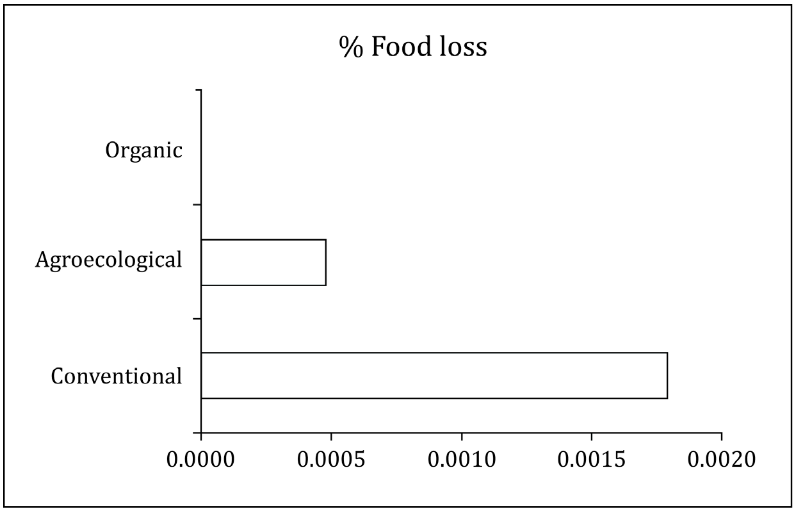

Figure A.9 — Wheat grain yield loss (%) in the three management systems

In maize, no grains were detected on the ground either before or after harvest across all sampling events and management systems. Yields, however, varied markedly between years and practices, ranging from 3,50 t/ha under organic management to 17,6 t/ha under conventional management in 2025. These findings reinforced the conclusion that major losses in maize occur during the growing season rather than at harvest and should therefore be classified as production losses.

From a methodological standpoint, the study revealed important limitations of pre-harvest loss measurements. Given the negligible amount of grain found on the ground, pre-harvest assessments were shown to provide little added value for cereals. In contrast, harvest-stage measurements were more reliable and operationally feasible. The experience also highlighted the influence of cultivar choice, climatic variability, machinery calibration, and operator skill on observed outcomes.

Overall, the results confirmed that production losses driven by stress factors throughout the crop cycle are far more significant than food losses occurring at harvest. While the FAO-recommended method remains feasible -particularly for post-harvest assessments- the study showed that its relevance may be limited in highly mechanized and industrialized systems, where farmers may perceive little benefit from labour-intensive measurements with marginal loss estimates.

To address these limitations, the case study proposed an alternative, simplified approach. This method is based on sampling small, well-defined areas within the field and manually collecting all plants to assess yield components (e.g., number of ears, grains per ear, grain mass). This allows the estimation of an attainable yield specific to the field and season, representing the maximum yield achievable under the farm's usual management practices. The difference between this attainable yield and the actual harvested yield provides an integrated estimate of losses occurring up to harvest, encompassing both production and food losses.

A.3.3 Adaptability of the methodology to other food typologies

The proposed methodology demonstrates strong potential for adaptation to other cereal crops, including barley, rye, oats, and sorghum, with only minor adjustments to sampling design and yield component assessment. With further refinement, it could also be extended to legumes and oilseeds, which share similar harvest mechanisms and loss dynamics.

A.3.4 Proposals to improve the current method

Opportunities for methodological improvement were identified. Firstly, greater emphasis should be placed on distinguishing clearly between production losses (occurring during the growing season) and food losses (occurring during and after harvest).

Secondly, repeated measurements across phenological stages are generally feasible only in research contexts and not in commercial farming. To overcome this, technological tools such as remote sensing, yield modelling, and spatial analysis is recommended, as these tools could enhance representativeness, capture the effects of machinery traffic, and enable scaling from small-plot observations to whole-field assessments.

Finally, looking to the future, climate change is expected to exacerbate production losses in cereal systems through increased drought, heat stress, and rainfall variability. While improvements in harvesting technology may marginally reduce mechanical losses, they are unlikely to offset the growing impact of climate-related stresses. This underscores the importance of methodologies that capture losses across the entire production cycle and support the development of more resilient cropping systems.

A.4 Meat and dairy

A.4.1 Description of the methodology developed for the case study

The Irish case studies used a mixed-methods approach that combined semi-structured interviews with four purposefully selected farmers (two beef, two dairy) and extensive secondary data from national and EU statistical sources, industry organizations, and agricultural reports.

Food loss measurement was aligned with the FOLOU framework through the Ready-to-Harvest (RH) functional model, which defines food loss relative to the point at which livestock are physiologically and economically ready for slaughter (beef) or lactation (dairy). For beef, RH was determined by finishing mass, age ranges, and EUROP carcass classification criteria. For dairy systems, RH occurred at the onset of lactation following successful calving, with milk production capability marking readiness. Sector-specific modifications were applied to accurately classify losses.

A.4.2 Results

The beef case studies revealed a food loss profile heavily concentrated in the post-harvest processing phase, with pre-slaughter losses being relatively minimal. Quantitative findings helped to determine the following guideline percentages:

- Ready for slaughter losses: carcass Rejection and Downgrades: 2-4 % of carcasses experienced rejection or significant downgrade.

- Slaughtering: offal Oversupply and Market Limitations: 8-12 % of edible offal was diverted to rendering or disposal, particularly during autumn peak slaughter periods.

- Slaughtering: specification Mismatches: 3-6 % of production experienced specification failures.

Dairy operations demonstrated losses spanning production and immediate post-harvest phases:

- Withdrawal Period Disposal: 1,5-3 % of annual milk production (equivalent to 12 000-24 000 litres per farm annually).

- Tank Contamination Events: 2-4 events per farm annually, resulting in 2 000-10 000 litres lost per incident.

- Collection Logistics Failures: 0,5-1 % of annual production.

The practical implementation of food loss measurement revealed several critical insights about current monitoring capabilities and limitations within Irish livestock systems. Firstly, farmers maintained comprehensive records for regulatory compliance (major milk disposal incidents, animal mortalities) but routine smaller losses (partial carcass downgrades or regular withdrawal period disposal) were inconsistently recorded. This likely leads to systematic underestimation of actual food loss levels in official statistics.

Secondly, the application of Ready to Harvest (RH) criteria revealed important differences in interpretation between production systems. Organic farmers consistently applied more conservative readiness thresholds, often extending finishing periods or holding milk longer to ensure quality standards were met. Conventional producers, on the other side, demonstrated more variable RH interpretation, with some prioritizing throughput efficiency over loss minimization.

Both dairy and meat sectors faced significant technological constraints in implementing comprehensive loss measurement. Dairy operations lacked real-time monitoring capabilities for critical quality parameters, while beef operations similarly lacked predictive assessment tools for identifying animals at risk of carcass rejection or downgrade.

The absence of integrated data management systems meant that loss information remained fragmented across different record-keeping systems, making comprehensive analysis difficult and reducing opportunities for proactive loss prevention.

A.4.3 Adaptability of the methodology to other food typologies

The methodology developed for Irish meat and dairy systems demonstrates strong transferability potential to other animal-source food commodities, with appropriate sectoral calibrations.

Sheep, poultry, egg, and aquaculture production systems share some conceptual alignment with the RH framework, but each requires targeted adaptation. Sheep meat systems closely parallel beef production in slaughter-readiness indicators and regional carcass use, though their seasonal nature demands temporal adjustments. Poultry systems differ more markedly due to rapid production cycles, narrow decision windows between readiness and processing, and heightened disease risk, making loss management more time-critical. However, their closed-system structure enables precise loss tracking but requires integration with biosecurity protocols.

Egg and aquaculture systems require more fundamental rethinking of the RH concept. Egg production operates on a continuous harvest model rather than discrete events, necessitating daily monitoring and adapted loss categories linked to quality, safety, and contamination risks. Aquaculture systems are even more environmentally sensitive, with losses strongly influenced by climate and water conditions. Continuous growth patterns and batch harvesting in aquatic environments mean the RH model would need substantial modification to remain applicable, particularly for forecasting and managing environmentally driven losses.

A.4.4 Proposals to improve the current method

The implementation of standardized, sector-specific readiness (RH) assessment tools would improve consistency and accuracy in framework application. The development of user-friendly mobile applications enabling farmers to record food loss events in real-time would address the current measurement blind spot identified in farmer recording practices. In addition, the establishment of systematic feedback loops between processing facilities and primary producers would significantly improve loss prevention capabilities.

The FOLOU framework should explicitly incorporate milk production systems in future revisions, acknowledging the dual nature of dairy operations as both continuous process and discrete harvest events.

The methodology's success in capturing sectoral nuances while maintaining framework consistency provides a foundation for broader application across animal-source food systems. The findings highlight the critical importance of context-sensitive approaches that can accommodate the diversity of production systems, market structures, and environmental conditions characterizing modern agriculture.

A.5 Salmon

A.5.1 Description of the methodology developed for the case study

The salmon case study applies and adapts a food loss measurement methodology to one of the most technologically advanced aquaculture systems globally: Norwegian farmed Atlantic salmon. In response to persistently high mortality levels -estimated at 15,4 % in 2024, equivalent to nearly 58 million fish- the methodology is designed to document how losses are currently recorded, identify their main drivers, and assess the effectiveness and transferability of existing monitoring systems. Rather than relying on direct field observation or manual loss audits, the approach leverages Norway's comprehensive regulatory reporting framework, as the physical characteristics of open sea-cage farming make visual observation of losses impractical.

Data collection combines desk research, analysis of public and private datasets, and semi-structured interviews with industry stakeholders and regulatory bodies. Seven interviews were conducted with Norwegian conventional salmon producers and key institutions, including the Directorate of Fisheries, the Veterinary Institute, and the Food Safety Authority, complemented by interviews with two organic salmon producers outside Norway. Quantitative loss data were sourced primarily from mandatory monthly reports submitted through the Altinn system and from AquaCloud, a private industry database covering approximately 40 % of national production. These sources provide complementary perspectives on aggregate loss levels and fine-grained mortality drivers.

The methodology focuses on the sea-based grow-out phase (stage 4 of the salmon production cycle, in Figure A.10, where the majority of mortality and food loss occurs. Losses are recorded through legally mandated daily registration of dead fish, which are physically removed from cages and processed into ensilage. Salmon are counted definitively only at two points -stocking into sea cages and final harvest- while daily mortality records and occasional delousing-related counts provide interim data. For the purposes of the FOLOU framework, food loss is defined as losses occurring once fish exceed 3 kg, reflecting market relevance. This differs from Norwegian regulatory practice, which calculates mortality as a proportion of fish at risk rather than fish slaughtered.

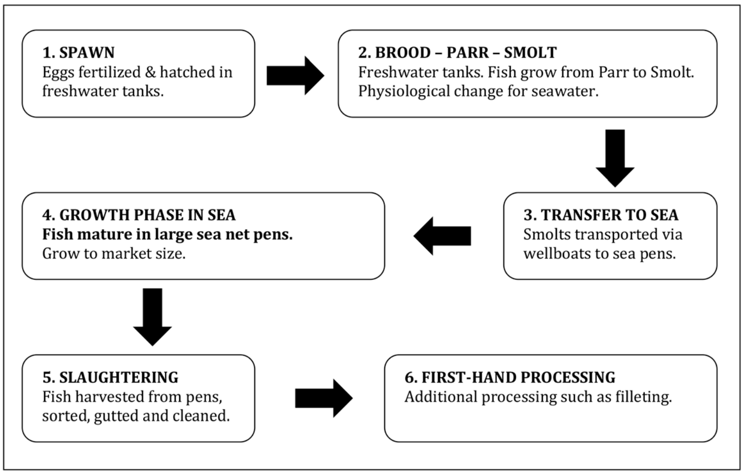

Figure A.10 — The Atlantic salmon production cycle

Food loss is calculated by aggregating four loss categories -mortality, escapees, discards, and an adjustment factor ("others")- and relating them to the number of slaughtered fish, with an additional estimate for post-harvest processing losses (approximately 3 %). While processing generates multiple waste streams, the methodology recognises that most by-products are valorised into feed, supplements, or pet food, meaning true food loss at this stage is relatively limited.

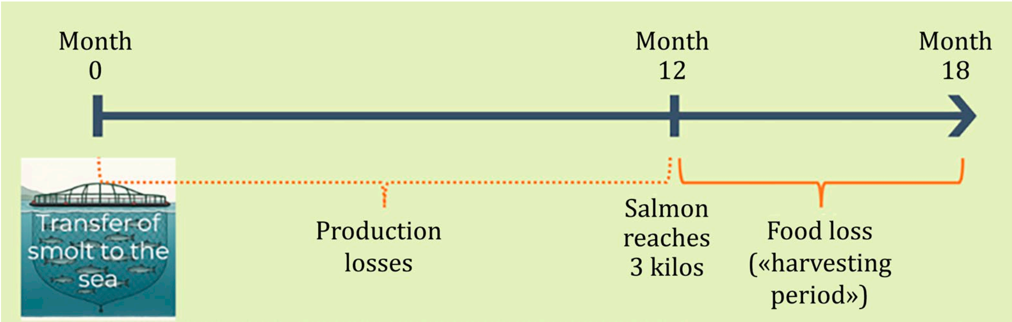

Figure A.11 — A stylized representation of the timeline for the salmon grow out stage

Because only at harvest can the number of slaughtered fishes be accurately compared with the initial number of smolt stocked, this moment provides the most reliable verification of true farm-level losses.

A.5.2 Results

The results demonstrate that food loss in salmon farming is both substantial and highly heterogeneous. Analysis of AquaCloud data reveals more than 360 distinct mortality causes, underscoring the biological and operational complexity of salmon aquaculture. Losses vary markedly across regions, seasons, production zones, farms, and production cycles, with local environmental conditions playing a decisive role. Timing is critical: losses occurring later in the grow-out phase result in disproportionately higher food loss due to the larger biomass of affected fish.

Seasonal patterns are evident across major mortality categories. Winter months are associated with ulcers, bacterial wounds, and handling-related injuries, while summer periods see higher losses linked to non-medicinal delousing treatments. Autumn peaks are often associated with gill diseases of uncertain origin. Some diseases, such as cardiomyopathy syndrome (CMS), exhibit more stochastic patterns, with limited seasonality. Data quality has improved over time, with the share of losses attributed to unknown causes declining significantly after 2022 as reporting practices and classification systems matured.

Food loss drivers also shift with fish size and lifecycle stage. For salmon above 3 kg, non-medical delousing treatments and CMS emerge as dominant contributors, reflecting both increased physiological vulnerability and the cumulative stress of production practices. Regional analysis shows that average monthly mortality ranges from approximately 1 % to 4 %, with generally lower rates in northern production zones compared to central regions. However, high standard deviations indicate considerable variability, masking large differences between individual farms and cohorts.

Farm-level analysis further highlights intra-farm variability across production cycles, with losses differing substantially between generations in terms of both timing and causes. Interviews with farmers corroborate quantitative findings, consistently identifying infectious diseases and delousing treatments as the most significant contributors to mortality. Climate-related stressors are expected to intensify these patterns, with warming waters, increased sea lice pressure, marine heatwaves, and harmful algal blooms likely to raise mortality rates and food loss across the production cycle in the coming decades.

A.5.3 Adaptability of the methodology to other food typologies

The Norwegian salmon case demonstrates that robust food loss measurement is feasible in complex, biologically sensitive systems when supported by strong regulation, standardised reporting, and technological monitoring. The methodology is particularly well suited for adaptation to other aquaculture sectors with similar characteristics, such as sea bass and sea bream farming in the Mediterranean. Core elements -including mandatory loss reporting, daily mortality tracking, biomass-based indicators, and detailed loss taxonomies- provide a transferable framework.

However, adaptation requires consideration of system-specific constraints, especially in regions with weaker regulatory oversight or less technological capacity. Aquaculture differs fundamentally from terrestrial livestock systems in that production occurs below the water surface, limiting direct observation and complicating loss verification.

Looking forward, advances in AI and sensor technologies are likely to reduce barriers to adoption across aquaculture typologies. Automated monitoring of fish numbers, health, and mortality could enable more consistent and scalable loss tracking.

A.5.4 Improvement opportunities for the methodology

The case study identifies several areas for improvement. A key limitation is the reliance on indirect counting between stocking and harvest, with daily mortality registration dependent on manual or semi-mechanical collection processes. Greater automation and real-time verification -particularly through AI-enabled underwater imaging- could significantly enhance precision, reduce labour demands, and improve temporal resolution of loss data.

Another improvement opportunity lies in further standardising and refining loss categorisation. Although the share of “unknown cause” mortality has declined, continued training and harmonisation across producers would improve comparability and analytical value. Integrating climate and environmental indicators more systematically into loss reporting would also strengthen the methodology’s capacity to anticipate future risks rather than merely document past losses.

Finally, post-harvest loss estimation remains based on static assumptions due to limited reporting from processing plants. While current estimates are considered reliable, more systematic data collection at this stage would improve overall accuracy and allow better differentiation between unavoidable by-products and true food loss.

A.6 Mussels

A.6.1 Description of the methodology developed for the case study

This case study examines food loss and production loss in Mediterranean mussel (*Mytilus galloprovincialis*) farming in the western Adriatic Sea, where mussel aquaculture represents nearly half of Italy’s total seafood production. Unlike intensive aquaculture systems, mussel farming in this region is entirely extensive, relying on natural environmental conditions without feed inputs, veterinary treatments, or organic/agroecological alternatives. The study therefore applies a methodology tailored to a low-input, ecosystem-dependent production system in which losses are strongly shaped by environmental variability and harvesting practices.

The production system is based on offshore long-line farming, where mussels grow on suspended ropes (“socks” or mesh sleeves) at depths of 4 m to 7 m. While technically simple, this system is highly efficient and environmentally beneficial, delivering ecosystem services such as water filtration, habitat enhancement, and carbon sequestration through shell formation. The methodological approach follows the full production cycle, from seed collection in June through an 11-month on-growing phase to final harvesting in May, with particular attention to distinguishing production losses from food losses.

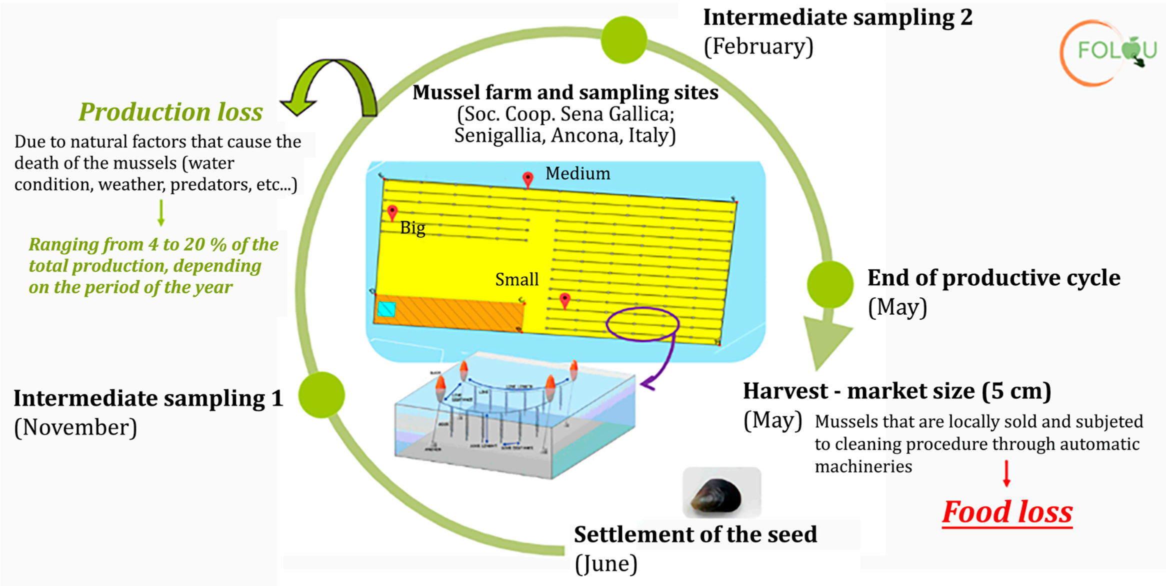

Figure A.12 — Scheme representing the whole productive cycle of mussels reared for the local distribution and the sampling points during the on-growing phase

The case study was conducted over two complete production campaigns (2023–2024 and 2024–2025) at the Sena Gallica cooperative, a major mussel producer serving local and national markets. Three farming sites -Small, Medium, and Big- were selected to reflect differences in initial seed size and spatial positioning. Sampling took place at four key moments: July (post-settlement), November and February (intermediate stages, including a partial harvest for national redistribution), and May (final harvest for local markets). At each sampling point, losses were quantified by measuring the proportion of dead mussels, capturing the cumulative effects of environmental stress, seasonal variability, and predation.

Loss classification is central to the methodology. All losses occurring before harvest, regardless of cause, were classified as production losses. Food loss was defined as mortality or irreversible damage occurring during harvesting and post-harvest handling. During the local May harvest, mussels were processed through an automated cleaning system that separates saleable mussels, seed for the next cycle, undersized dead mussels, and dead or damaged market-size mussels. Detailed mass-based analyses of nine socks allowed precise quantification of each category, enabling a clear distinction between recoverable outputs and true food loss.

A specific methodological challenge arises from the February harvest, during which undersized mussels are collected for transport to other Italian regions to complete their growth or, in some cases, to be sold directly.

To capture food loss beyond mortality alone, the methodology incorporated an experimental assessment of transport-induced stress and quality degradation. A controlled simulation of refrigerated transport examined how mussel position within stacked pallets affected physiological stress, tissue integrity, and marketability. This qualitative dimension expands conventional food loss assessment by recognising that loss may occur through reduced quality and shelf life, not only through death.

A.6.2 Results

Analysis of the local May harvest showed that the majority of biomass -approximately 77 %- consisted of saleable, cleaned mussels. A substantial fraction (around 15 %) comprised mussel seed, which, although not sold, is retained as a valuable input for the next production cycle. Dead undersized mussels accounted for less than 1 % and were classified as routine production losses. True food loss was limited to dead market-size mussels and those irreparably damaged during the cleaning process, together representing slightly over 5 % of sock biomass but less than 1,1 % of total farm production.

Beyond quantitative loss estimates, the results highlight the complexity of loss classification in mussel farming, particularly during the February harvest, where production loss and food loss may overlap. By incorporating physiological and quality indicators, the study broadens the concept of food loss to include deterioration that may reduce marketability even when mussels remain alive.

A.6.3 Adaptability of the methodology to other food typologies

The mussel loss quantification methodology is highly specific to this production system and is not easily transferable to other food typologies. Mussel farming involves unique features -such as live harvesting, automated cleaning as a major loss point, and extensive offshore growth- that differ fundamentally from other aquaculture and livestock systems. The central role of the cleaning process in generating food loss, and the importance of live transport in determining product quality, limit direct applicability elsewhere.

Nevertheless, the methodological principles of distinguishing production loss from food loss and incorporating quality degradation alongside mortality offer conceptual insights that could inform other live seafood sectors. However, significant adaptation would be required to account for differences in biology, harvesting, and post-harvest handling.

A.6.4 Proposals to improve the current methodology

For mussel farming, the methodology could be strengthened by integrating biological loss data with high-resolution meteorological and marine environmental data collected near farming sites. Linking mortality and productivity trends to parameters such as temperature, salinity, pH, oxygen levels, and chlorophyll concentration would improve causal understanding and enhance predictive capacity.

Annex B
(informative)

Classification of economic activities

Table B.1 presents the list of economic activities that need to be quantified for the analysis of food losses in primary production, within the recommended Divisions 01 and 03 by the Delegated Decision (EU) 2019/1597 [10]. This table also defines the priority level of each activity depending on its potential to generate food losses.

Table B.1 — Economic activities included in NACE Divisions 01 and 03

Division Code	Group Code	Class Code	Class Name	Priority
SECTION A — AGRICULTURE, FORESTRYAND FISHING				
01			**Crop and animal production, hunting and related service activities**	
	01.1		Growing of non-perennial crops	
		01.11	Growing of cereals (except rice), leguminous crops and oil seeds	HP
		01.12	Growing of rice	HP
		01.13	Growing of vegetables and melons, roots and tubers	HP
		01.14	Growing of sugar cane	HP
		01.15	Growing of tobacco	NA
		01.16	Growing of fibre crops	NA
		01.19	Growing of other non-perennial crops	NA
	01.2		Growing of perennial crops	
		01.21	Growing of grapes	HP
		01.22	Growing of tropical and subtropical fruits	HP
		01.23	Growing of citrus fruits	HP
		01.24	Growing of pome fruits and stone fruits	HP
		01.25	Growing of other tree and bush fruits and nuts	HP
		01.26	Growing of oleaginous fruits	HP
		01.27	Growing of beverage crops	HP
		01.28	Growing of spices, aromatic, drug and pharmaceutical crops	HP
		01.29	Growing of other perennial crops	NA
	01.3		Plant propagation	
		01,30	Plant propagation	NA

Division Code	Group Code	Class Code	Class Name	Priority
	01.4		Animal production	
		01.41	Raising of dairy cattle	HP
		01.42	Raising of other cattle and buffaloes	HP
		01.43	Raising of horses and other equines	LP
		01.44	Raising of camels and camelids	LP
		01.45	Raising of sheep and goats	HP
		01.46	Raising of swine/pigs	HP
		01.47	Raising of poultry	HP
		01.49	Raising of other animals	LP
	01.5		Mixed farming	
		01.50	Mixed farming	HP
	01.6		Support activities to agriculture and post-harvest crop activities	
		01.61	Support activities for crop production	NA
		01.62	Support activities for animal production	NA
		01.63	Post-harvest crop activities	NA
		01.64	Seed processing for propagation	NA
	01.7		Hunting, trapping and related service activities	
		01.70	Hunting, trapping and related service activities	HP
03			**Fishing and aquaculture**	
	03.1		Fishing	
		03.11	Marine fishing	HP
		03.12	Freshwater fishing	HP
	03.2		Aquaculture	
		03.21	Marine aquaculture	HP
		03.22	Freshwater aquaculture	HP
HP: High priority of being measured.				
LP: Low priority of being measured.				
NA: Not applicable				

Table B.2 shows an example of the combined use of NACE Class and CPA code, where NACE Class 01.11 (Growing of cereals (except rice), leguminous crops and oil seeds), can be disaggregated into 9 or 29 different food product categories, depending on the 5 or 6-digit CPA coding.

Table B.2 — Example of combined use of NACE classes and CPA codes

NACE classes	5-digit CPA code	6-digit CPA code
D 01.11 - Growing of cereals (except rice), leguminous crops and oil seeds	01.11.1 Wheat	01.11.11 Durum wheat 01.11.12 Wheat, except durum wheat
	01.11.2 Maize	01.11.20 Maize
	01.11.3 Barley, rye and oats	01.11.31 Barley 01.11.32 Rye 01.11.33 Oats
	01.11.4 Sorghum, millet and other cereals	01.11.41 Sorghum 01.11.42 Millet 01.11.49 Other cereals
	01.11.5 Cereals straw and husks	01.11.50 Cereals straw and husks
	01.11.6 Green leguminous vegetables	01.11.61 Beans, green 01.11.62 Peas, green 01.11.69 Other green leguminous vegetables
	01.11.7 Dried leguminous vegetables	01.11.71 Beans, dry 01.11.72 Broad beans, dry 01.11.73 Chickpeas, dry 01.11.74 Lentils, dry 01.11.75 Peas, dry 01.11.79 Pulses (dried leguminous vegetables) n.e.c.
	01.11.8 Soya beans, groundnuts and cotton seed	01.11.81 Soya beans 01.11.82 Groundnuts, in shell 01.11.83 Groundnuts, shelled 01.11.84 Cotton seed
	01.11.9 Other oil seeds	01.11.91 Linseed 01.11.92 Mustard seed 01.11.93 Rape or colza seed 01.11.94 Sesame seed 01.11.95 Sunflower seed 01.11.99 Other oil seeds n.e.c.

Tables B.3 and B.4 show an example of the conversion of NACE classes and CPA codes into ISIC and CPC codes.

Table B.3 — Example of conversions for certain food items according to NACE and ISIC codes

NACE Classes		ISIC Codes	
Class Code	Class Name	Class Code	Class Name
01.11	Growing of cereals (except rice), leguminous crops and oil seeds	0111	Growing of cereals (except rice), leguminous crops and oil seeds
01.12	Growing of rice	0112	Growing of rice
01.13	Growing of vegetables and melons, roots and tubers	0113	Growing of vegetables and melons, roots and tubers
01.14	Growing of sugar cane	0114	Growing of sugar cane
01.15	Growing of tobacco	0115	Growing of tobacco
01.16	Growing of fibre crops	0116	Growing of fibre crops
01.19	Growing of other non-perennial crops	0119	Growing of other non-perennial crops

Table B.4 — Example of conversions for certain food items according to CPA and CPC codes

6-digits CPA Codes		4- & 5-digits CPC Codes	
Code	Name	Code	Name
01.11.11	Durum wheat	0111	Wheat
01.11.12	Wheat, except durum wheat	0111	Wheat
01.11.20	Maize	0112	Maize (corn)
01.11.31	Barley	0115	Barley
01.11.32	Rye	0116	Rye
01.11.33	Oats	0117	Oats
01.11.41	Sorghum	0114	Sorghum
01.11.42	Millet	0118	Millet
01.11.49	Other cereals	01192	Buckwheat
01.11.49	Other cereals	01193	Fonio
01.11.49	Other cereals	01194	Quinoa
01.11.49	Other cereals	01195	Canary seed
01.11.49	Other cereals	01199	Other cereals n.e.c.

Tables B.5, B.6 and B.7 provide examples of the prioritisation for crops, animal husbandry and fishery. In the case of aquaculture and fishing, it is recommended to name the product categories by its common type (e.g. tuna, anchovy, mussels…).

Table B.5 — Example of main crops in a region

NACE Classes	Food commodity (CPA)	Total cultivated hectares (ha)	Total annual production (tonnes in live mass)
01.11 - Growing of cereals (except rice), leguminous crops and oil seeds	01.11.1 Wheat	160 000	420 000
01.12 - Growing of rice	01.12.10 Rice, not husked	9 750	83 500
01.13 - Growing of vegetables and melons, roots and tubers	01.13.14 Lettuce	5 200	531 500
01.13 - Growing of vegetables and melons, roots and tubers	01.13.51 Potatoes	3 370	99 000
01.13 - Growing of vegetables and melons, roots and tubers	01.13.21 Watermelons	950	47 600
01.23 - Growing of citrus fruits	01.23.13 Oranges	17 380	480 000
01.24 - Growing of pome fruits and stone fruits	01.24.10 Apples	1 980	32 300

Table B.6 — Example of main livestock farms in a region

NACE Classes	Food commodity (CPA)	Number of farms	Total annual production (tonnes)
01.47 Raising of poultry	01.47.11 Chickens, live	52	22 150
01.42 Raising of other cattle and buffaloes	01.42.1 Other cattle and buffaloes, live	32	21 400
01.46 Raising of swine/pigs	01.46.10 Swine, live	36	7 925

Table B.7 — Example of companies/vessels in the fishing and aquaculture sector in a region

NACE Classes	Food commodity	Number of companies/vessels	Total annual production (tonnes)
03.11 Marine fishing	Tuna	7	340
03.11 Marine fishing	Anchovy	12	6 500
03.11 Marine fishing	Hake	14	7 300
03.11 Marine fishing	Sardine	9	1 250
03.21 Marine aquaculture	Salmon	4	723
03.22 Freshwater aquaculture	Trout	5	926

Bibliography

[1] FAO. *Global food losses and food waste: Extent, causes and prevention.* Food and Agriculture Organisation of the United Nations, Rome, 2011

[2] Tracking progress on food and agriculture-related SDG indicators FAO. 2023

https://www.unsdglearn.org/resources/tracking-progress-on-food-and-agriculture-related-sdg-indicators-2023/

[3] FAO. (2019) The state of food and agriculture 2019 — Moving forward on Food Loss and Waste Prevention. FAO, Rome, 2019, 178 pages. http://www.fao.org/publications/sofa/en/

[4] FOLOU. (2026). *Food loss Definitional Framework*. CORA.RDR, Catalan Open Research Area. https://dataverse.csuc.cat/dataverse/folou

[5] FOLOU. (2026), *Food Loss Quantification Manual*. https://www.folou.eu/document/#deliverables

[6] Codex Alimentarius Commission. *CAC/GL 81-2013: Guidance for governments on prioritizing hazards in feed*. FAO and WHO, 2013

[7] ISO 20001:2026[4], Food loss and waste management system — Requirements for the minimization of food loss and waste across the food value chain *(under preparation)*

[8] ISO 22000:2018, *Food safety management systems — Requirements for any organization in the food chain*

[9] Regulation (EC) No. 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law

[10] Commission Delegated Decision (EU) 2019/1597 of 3 May 2019 supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste

[11] Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste

[12] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

[13] Eurostat (2024). Nomenclature of territorial units for statistics. NUTS classification update

[14] Eurostat (2023). Nomenclature statistique des activités économiques dans la Communauté européenne. NACE classification update

[15] Commission Delegated Regulation (EU) 2024/3103 of 2 September 2024 amending Regulation (EC) No 451/2008 of the European Parliament and of the Council as regards updating the classification of products by activity (CPA)

[4] Under development. Stage at time of publication: ISO/FDIS 20001:2026.

[16] United Nations Statistics Division (UNSD). *International Standard Industrial Classification of All Economic Activities (ISIC)*. Series M: Statistical Papers No. 4/Rev.4. New York, 2008

[17] United Nations Statistics Division (UNSD). *Central Product Classification. (CPC)* Series M: Statistical Papers No. 77. Ver. 2.1. New York, 2015

[18] Francioni et al. Scarcity of P-fertilisers: Humic-complexed phosphate as an adaptive solution for wheat and maize under rainfed conditions. *Eur. J. Agron*. 2024, 156 p. 127080

[19] Johnson L.K., Dunning R.D., Bloom J.D., Gunter C.C., Boyette M.D., Creamer N.G. Estimating on-farm food loss at the field level: A methodology and applied case study on a North Carolina farm. *Agric. Syst*. 2018, 137. DOI:10.1016/j.resconrec.2018.05.017

[20] Maes W.H. Practical Guidelines for Performing UAV Mapping Flights with Snapshot Sensors. *Remote Sens*. 2025, 17 p. 606 https://doi.org/10.3390/rs17040606

[21] FAO 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), 2018