FOLOU
D4.1 – Robust and harmonised measurement and estimation methodology for quantifying food loss at the primary production stage

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Food Loss Quantification Manual

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Abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
CPA	Classification of Products by Activity
CPC	Central Product Classification
EC	European Commission
EM	Edible and Marketable
EnM	Edible but Not Marketable
EU	European Union
EUROSTAT	European Statistical Office
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization
FG	Focus Group
FL	Food Loss
FLDF	Food Loss Definitional Framework
FLQM	Food Loss Quantification Manual
FLW	Food Loss and Waste
FW	Food waste
GCP	Ground Control Points
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HP	High Priority
ISIC	International Standard Industrial Classification of All Economic Activities
ISO	International Organization for Standardization

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Abbreviation	Meaning
LP	Low Priority
MACS-G20	Meetings of Agricultural Chief Scientists of G20 States
NA	Not applicable
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
nEnM	Neither Edible Nor Marketable
NIR	Near-Infrared light
NORCE	Norwegian Research Centre
NUTS	Nomenclature des Unités Territoriales Statistiques
PGFL	Potential Generator of Food Loss
PPK	Post-Processed Kinematic
RGB	Red Green Blue
RTK	Real-Time Kinematic
UAA	Utilised Agricultural Area
UAV	Unnamed Aerial Vehicle
UK	United Kingdom
UNEP	United Nations Environment Programme
UNIVPM	Università Politecnica delle Marche
USA	United States of America
VIS	Visible light
WP	Work Package
WRI	World Resources Institute
WWF	World Wide Fund for Nature
YOLO	You Only Look Once

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Executive summary

The issue of food loss and waste (FLW) encompasses social, environmental, and economic dimensions. Since 2018, its inclusion in public policies has gained momentum, with the definition of the term "food waste" at EU level (Directive (EU) 2018/851) and the obligation for Member States to measure it annually through a common methodology defined in Delegated Decision 2019/1597. However, this European legislation on food waste measurements does not cover the entire agri-food value chain. By starting at the post-harvest stage, it leaves earlier stages unmonitored and the true magnitude of the problem at the primary production stage unknown. In fact, food discarded at this stage is what the FAO refers to as "food loss", a term that has not yet been defined at EU level.

In this context, the **FOLOU project** aims to contribute to:

- Unlock the systemic transition of EU food systems by establishing the necessary mechanisms to measure and estimate food losses at the primary production stage, encompassing agriculture, aquaculture, and fisheries;
- Monitor and report food losses at Member State and European levels;
- Assess the magnitude and impacts of food losses, as well as identify their key drivers.

The objective of this Deliverable 4.1, entitled "Robust and harmonised measurement and estimation methodology for quantifying food loss at the primary production stage" hereinafter referred to as "***Food Loss Quantification Manual"***, is to present a knowledge manual addressing this core measurement objective across different territories within the European Union, as well as across different food types and production systems, while continuously seeking a balance between robustness and feasibility.

The **methodology** used to prepare this manual included several stages. The first draft was developed based on the expertise of the project partners, supported by the results of a literature review on methodologies for measuring food loss at farm level. Building on this initial draft, two further versions were developed incorporating contributions from other project work packages: the work carried out in the development of the food loss data repository (WP1); the identification of the main drivers of food loss (WP2); the contribution of new technologies for measuring food loss (WP3); the testing of the methodology developed in this manual through five case studies: the fruit and vegetable sector in Spain, cereals and pulses in Italy, roots, tubers and oil crops in Belgium, the aquaculture and fisheries sector in Italy and Norway, and the meat and dairy sector in Ireland and Belgium (WP4); and the exchange of experiences through the Twinning Regions Programme (WP7). Furthermore, this manual has been reviewed and validated by 24 international experts external to the project.

The process resulted in the development of the ***Food Loss Quantification Manual***, presented in this report. The manual provides necessary information to diagnose food loss at territorial diagnosis through direct measurement, as well as to measure it at the individual farm level.

The first chapter addresses **what to measure** by presenting the FOLOU project's proposed definition of "food loss", which establishes what should be measured at the primary production stage. The proposed food loss definition is as follows:

> ***Food loss is any harvest-mature plant, animal or living being 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.***

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To determine **where measurement should take place**, the second chapter describes how to conduct a territorial food loss diagnosis. This is mainly done by identifying the most predominant economic activities (NACE codes) in the territory that are potential generators of food loss. The manual proposes an improvement to the measurement planning outlined in Delegated Decision 2019/1597, encouraging the disaggregation of NACE categories to enable measurement and reporting at the most specific level possible by food commodity (using CPA codes). For the prioritised NACE classes, the regions with the highest concentration of these activities within the territory are identified, allowing potential farms for direct measurements to be located.

The main sections focus on **how and when to measure.** Accordingly, recommendations have been provided for measuring losses at the **level of plots, farms, and ponds,** and subsequently at farm level. This process begins with farmers interviews, which serves three purposes: i) to collect perceptual information, ii) to identify possible drivers of food loss, and iii) to coordinate with the farm's responsible person for direct measurement activities. These interviews provide contextual information that is essential for understanding the issue of food losses. This information must be complemented with quantitative data obtained through direct quantification. The manual provides recommendations on the main aspects of direct measurement, such as the establishment of a sampling size and the collection of pre-harvest and harvest samples, their classification into loss categories, and weighing. Subsequently, the sampling data are extrapolated to the entire field.

Once information has been collected at farm level, it is necessary to extrapolate the calculations to **an entire territory**. The fourth chapter describes both the extrapolation process and how to share data using NACE and CPA codes for standardisation.

In addition, **emerging technologies** may increasingly support and facilitate this process. The fifth chapter outlines how new technologies can contribute to the measurement of food loss, whether by guiding and supporting manual measurement or through autonomous image-based measurement.

The annexes contain supplementary materials and methodological considerations for measuring food loss in specific food commodities.

In conclusion, this manual aims to harmonise the process of measuring food loss, primarily within the European Union, and it is based on work carried out over four years, building on consensus among experts involved in the FOLOU project and validation by external experts.

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A. General objective of the manual

The main objective of the FOLOU project is to provide methodologies and definitions related to material flows that are lost throughout the agri-food chain and are currently "hidden" due to not being included in the minimum requirements for measuring food waste (FW) in Member States, as outlined in the Delegated Decision [1].

The purpose of the Food Loss Quantification Manual (FLQM) is to serve as a reference for public administrations, private entities, research centres, NGOs, as well as for farmers, livestock breeders, and companies involved in fishing/aquaculture, who wish to tackle the challenge of quantifying food loss (FL) in their organisation, agricultural operation, or entire territory. Thus, this document aims to address all possible flows that are not covered by the Delegated Decision 2019/1597 for the uniform measurement of levels of FW, regardless of whether they fit into the category of FL or not. These flows are not only meant to be identified but are especially intended to be measured. By doing so, it can be demonstrated that quantification is indeed possible, and that FL deserves to be considered when setting reduction targets across the entire agri-food chain, not just the portion of the chain that the European Union currently categorises under the term "food waste".

While the primary focus is on providing tools and recommendations for measuring FL within the European Union, the goal is also for many of these recommendations to be adaptable to other regions. To achieve this, the manual has been developed through consensus among various experts, studies, and case studies that are validating and testing many of these methodologies across different commodity groups and emerging technologies. This effort to seek consensus is aimed at facilitating the standardisation of measurement processes, which enhances the comparability of results and fosters synergies between studies and initiatives, enabling a broader understanding of the issue beyond the scope of a single study.

Finally, it is important to highlight that there are other flows that do not fall under the definitions of food loss or food waste, such as those food products ultimately destined for animal feed or the so-called production losses. In the context of a Circular Economy, these flows also deserve to be analysed as other pieces of the puzzle, always aiming for the best possible final use and destination, within a continuous improvement process for managing all existing flows.

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B. Instructions on how to use this manual

The FLQM revolves around four main questions for the quantification process: "What?", "Where?", "How?", and "When?". These answers must align with the measurement recommendations for FW established by the European Commission (Delegated Decision 2019/1597). This manual proposes several improvements to these recommendations, enabling more precise identification of potential points of food loss generation.

The questions "What?" and "Where?" are each given their own chapter in the manual (**Chapters 1 and 2,** respectively), while the responses to the questions "When?" and "How?" are combined in a single chapter (**Chapter 3**). **Chapter 4** explains how to extrapolate data from direct measurements to the territorial level. **Chapter 5** includes a description of emerging technologies that may contribute to the quantification of FL, while **Chapter 6** outlines the main limitations and conclusions of the FLQM.

The Annexes (**pag. 116**) contains the tables and templates used to collect information through interviews with farmers. It also includes the methodological considerations for measuring FL among the commodities tested in the WP4.2 case studies.

The reading of the entire document is intended for public administrations and other entities aiming to carry out FL measurement activities at a territorial level. However, entities, such as research centres, companies or individual farmers, seeking only to quantify losses on a specific plot, may skip Chapters 2 and 4, which are aimed at quantification and extrapolation at the territorial level.

Indeed, the manual outlines the need for direct in-situ measurements in crops. This follows a series of steps, including interviews with farmers to better understand their reality and the extrapolation of results to the entire territory. Such steps are summarised in the boxes below and allow the reader to directly go to the chapter (Ch.) and subchapter of interest through hyperlinks highlighted in blue (Figure 1)

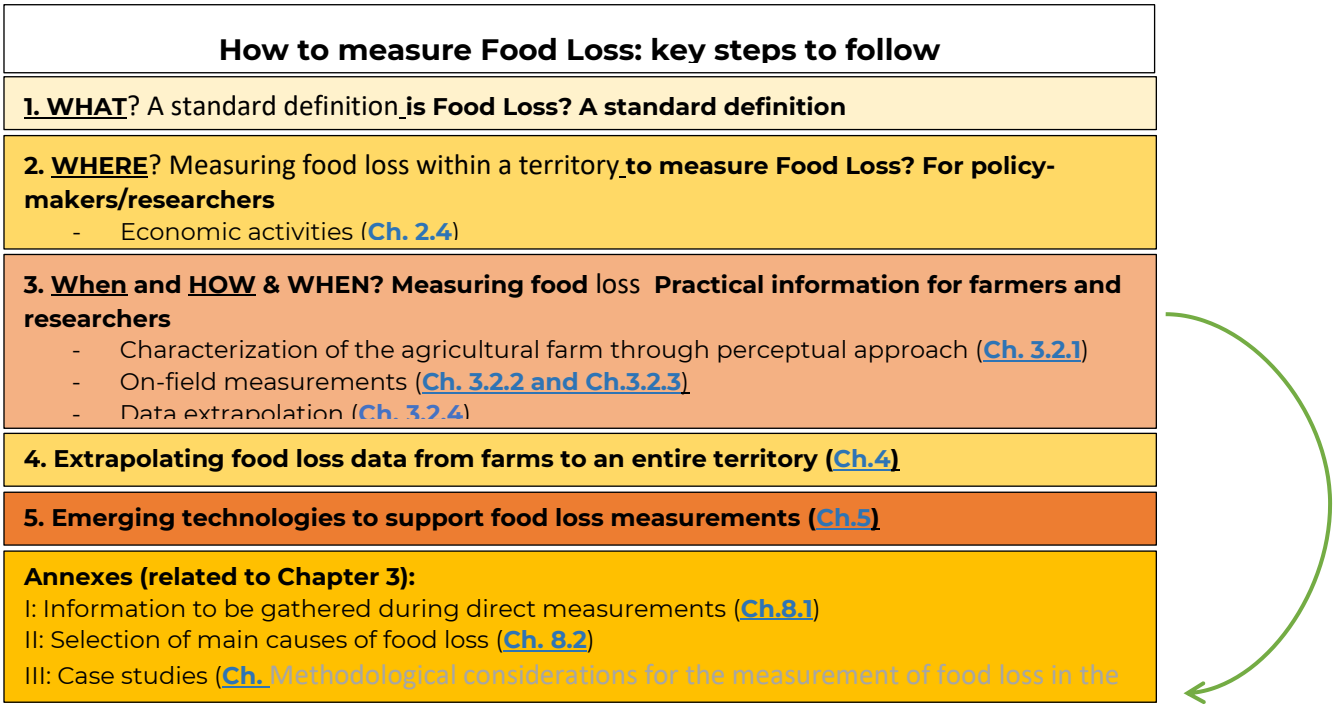

Figure 1. How to measure Food Loss: key steps to follow. The figure includes hyperlinks (text highlighted and in blue) to directly go to each chapter and subchapter. The annexes are directly related to Chapter 3. (How), as they contain explicative cases on how to perform the measurements. Source: Authors' owns elaboration.

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C. Methodology of the Food Loss Quantification Manual

The process of developing the FLQM has involved a series of iterations, feedback loops and continuous validation over a period of three and a half years (2023-2026). During this time, several key milestones have played a central role, drawing on a range of sources and experiences. Figure 2 presents the methodology followed to elaborate the FLQM.

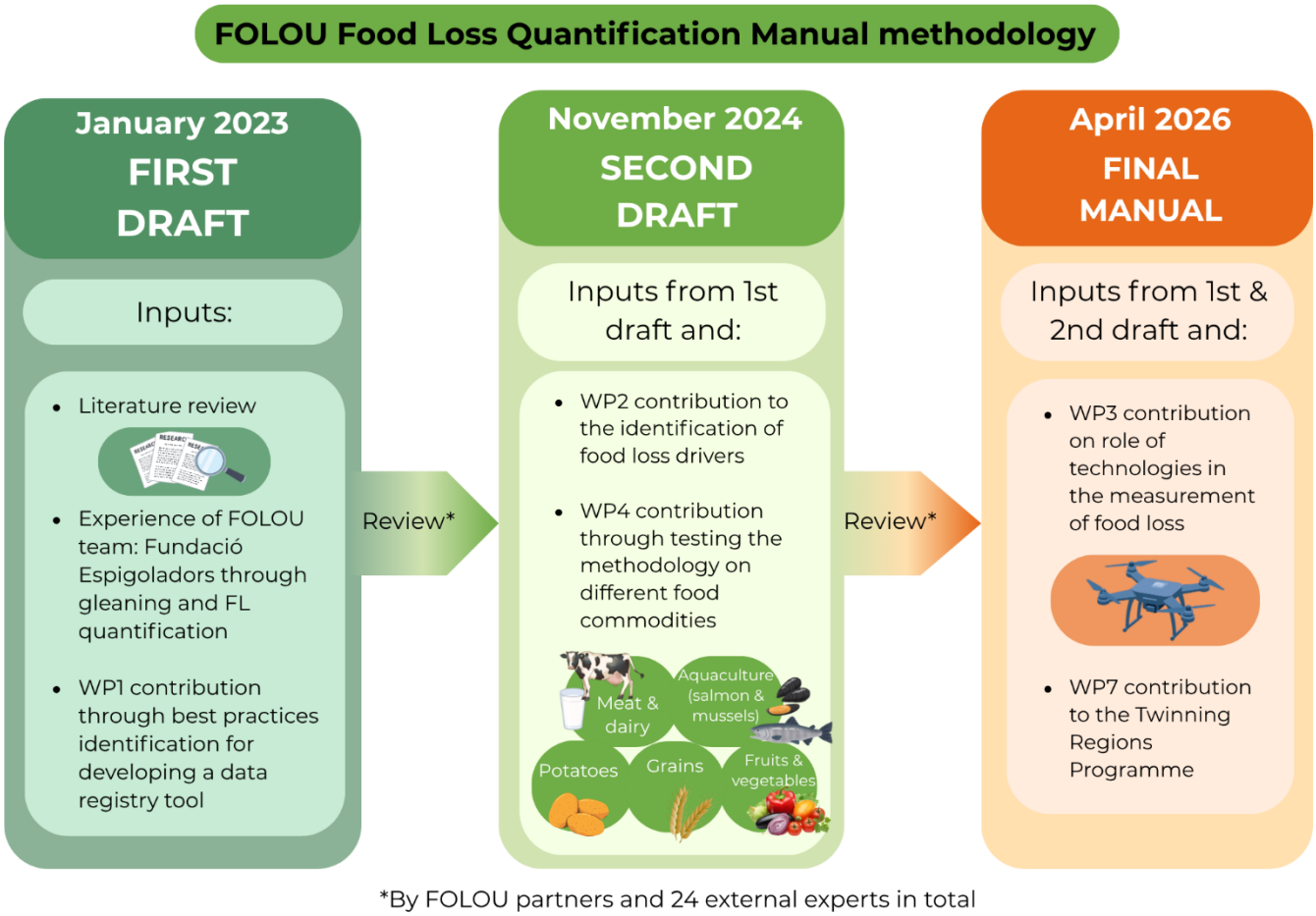

Figure 2. Methodology followed to elaborate the Food Loss Quantification Manual (FLQM)

C.1. **Development of the first draft of the manual.**

The development of the manual started in January 2023, with the first draft completed by September of the same year. During this phase, the manual was primarily developed based on the literature review conducted for the Food Loss Definitional Framework[1].

This literature review was conducted between March and May of 2023, consisting of grey and scientific literature, accessed through SCOPUS, Google Scholar and a snowballing process. For the search, the terms "food loss" and "food waste" were used together with "quantification", "measurement", and "estimation" as well as with "primary production",

[1] The complete *Food Loss Definitional Framework* document developed under the FOLOU project is forthcoming on Catalan Open Research Area (CORA).

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"farm", "field", "agriculture", "aquaculture" and "fisheries," resulting in the following search string for SCOPUS[2]:

> (TITLE-ABS-KEY("food loss" OR "post-harvest loss" OR ("food waste" AND ("primary production" OR farm OR field OR agriculture OR aquaculture OR fisheries)))
>
> AND TITLE-ABS-KEY(quantification OR measurement OR estimation)
>
> AND TITLE-ABS-KEY("primary production" OR farm OR field OR agriculture OR aquaculture OR fisheries))

The search was limited to sources published in English. Articles were considered "in-scope" if they provided data on the quantity and/or composition of FL at any point in primary production, and/or described the methods used for quantification, and/or provided a definition of food loss that encompasses primary production. Through the snowballing process, also scientific and grey literature in Spanish language were included.

Using this method, a total of 712 articles were identified (227 through Scopus and 485 through Google Scholar). No date restriction was applied. Of these, 637 records were discarded due to being out of scope or duplicated, giving a final result of 117 articles to be reviewed. After the review process, 73 relevant articles were selected to be used for the development of the definition and for the elaboration of the manual. The discard criterion is based on not meeting any of the previously stated inclusion criteria: providing data on the quantity and/or composition of FL at any stage of primary production, describing the quantification methods used, or offering a definition of FL that includes primary production.

All of them were categorised according to various parameters, including the methods used for quantifying losses (i.e., direct or indirect measurement types). Particular attention was given to direct methods (especially weighing), the sub-stages of the supply chain covered and the food commodities identified within the FOLOU project. In addition, the methodologies based on interviews and surveys found in the literature served as a reference for the design of the interviews proposed in this manual to further complement the quantification process.

The findings of this literature review were cross-checked against the practical experience of the Fundació Espigoladors team, particularly its gleaning unit. The gleaning team brings twelve years of direct field experience, conducting loss assessments and engaging with the sector on this issue. This comparison served to validate and contrast the more perceptual aspects of the analysis, and to identify the information considered most relevant for data collection on FL.

In addition, an effort was made to assess the actual costs and operational implications associated with direct measurement of losses across different crop types, as well as the feasibility of establishing a generalised protocol for FL measurement in agricultural production. This is supported by the team's experience of conducting a total of 1,527 gleanings over the past twelve years. Quantitative and qualitative data (including FL drivers) have been collected for 547 of them.

A third stream reinforcing the previous two has been the collective experience of the entire FOLOU team. Through their diverse areas of expertise, they contributed to the development of the loss quantification protocol. In this initial phase, particular emphasis was placed on alignment with the partners involved in WP1, both in relation to the design and collection of data for the repository and the development of the FOLOU FL registry.

[2] Due to the limitations of Google Scholar, the search on this web source was conducted using keywords instead, as explained in the text, and there are no equivalent strings.

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This synergy proved essential, as the information generated through the loss quantification protocol would ultimately feed into the registry. Therefore, the insights derived from the literature review and the best practices identified by WP1 in developing an effective registry tool also contributed to improving the manual itself. Specifically, they helped identify the key elements that must be captured during the loss measurement process to ensure that they can be properly reported and recorded.

C.2. Review of the first draft

This first draft of the manual was initially shared with all partners involved in the FOLOU project, across the different tasks and Work Packages. The aim was to gather their feedback and insights based on their experiences during the early stages of the project, ensuring alignment with the overall objective of defining, measuring, reporting, and assessing the environmental impact associated with the analysis of FL.

Within the review and feedback process from FOLOU partners, the collaboration with WP3, focused on innovative tools for measuring FL, was particularly relevant. This was essential to define the measurement window for losses in alignment with the EU definition of FL, as well as to identify other emerging technologies that might not strictly fit the loss definition but could contribute to a broader analysis of the issue across the entire food chain, providing a more holistic view of the agri-food system.

These technologies proved especially relevant in stages preceding the formal concept of FL, as they could ultimately affect crop yields and potentially accelerate future FL processes. Additionally, another key area of interest and synergy was understanding how these technologies could support and enhance the loss measurement process by identifying the specific phases of the protocol where innovative tools could add value and improve the overall assessment.

Another avenue for enhancing and expanding the loss quantification protocol has been through the case studies conducted within the FOLOU project (Task 4.2). Six case studies were established to measure FL across seven different food types in various territories of the European Union. This initial manual thus served as a general foundation from which it could be refined and adapted to the specific circumstances of each case study and food type:

- Vegetables and fruit sector case study. This case study was conducted in Spain (Catalonia region) by Fundació Espigoladors. Spain is one of the major producers of fruits and vegetables. The specific products initially selected for quantification were apples and pears, tomatoes, peaches and nectarines, and the cabbage and lettuce sector.
- Grain and pulses sector. This case study was conducted in Italy and led by Università Politecnica delle Marche (UNIVPM), where FL from maise and wheat were analysed.
- Roots, tubers and oil crop sector case study. This case study was conducted in Belgium and led by Ghent University. The food commodity considered as a reference for measuring losses within this sector was potatoes.
- Aquaculture and Fisheries sector. Within this sector, two different case studies were established:
    - The study of FL occurring during salmon farming in Norway, a case study led by NORCE.
    - The analysis of FL in mussel farming in Italy, a case study led by Università Politecnica delle Marche (UNIVPM).

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- Meat and dairy sector case study. This case study focuses on two different types of food: meat and milk. FL generated by these commodities was analysed in Ireland, Belgium, and the Netherlands. The case study is led by the University of Limerick.

All of these case studies began in June 2023 and accompanied the development of the quantification manual until its completion. Within this process, two key aspects were addressed: the **adaptation of the FL concept** to each specific food commodity, and the most **appropriate methodology for each**, considering reliability through the use of direct methods and practicality, enabling other organisations and regions to quantify FL in the future. Therefore, it is not only important to provide data on losses for each of these food commodities, but what is truly relevant for the manual has been the experience gained in measuring these losses.

Another channel for feedback and validation of this first version of the manual has been through a network of external reviewers, which has grown and strengthened its collaboration over the past three years. In this stage, spanning from the preparation of the first draft to the development of the second, the network initially comprised a total of 86 experts with diverse profiles, including public administrations, universities and research centres, independent researchers and consultants, civil society organisations, and private companies. This network has been developed and expanded through the following channels:

- One of the main channels has been through the literature review conducted. All corresponding authors of these papers using weighing methods and standardisation processes were contacted, briefly introducing the context of the European project and, within it, the opportunity to collaborate on both the quantification manual and the definitional framework of FL.

- Beyond the papers identified in the previous stage, specific outreach was also conducted with organisations and leaders of international initiatives aimed at standardising FL and waste quantification processes, such as the international FLW Standard [2], the upcoming ISO 20001 and ISO 20008 standards, members of the former European FUSIONS project, and those responsible for FL and waste analyses at FAO and UNEP identified within WP7. In all cases, the objective was to explore avenues for collaboration with FOLOU, primarily to gather feedback on the draft of the quantification manual, as well as on the definitional framework.

- Within the Meetings of Agricultural Chief Scientists of G20 States (MACS-G20), the Initiative on Food loss & Food Wastes was established, and within it, a web portal regarding FLW research and experts was created. The web portal provides a database of experienced individuals working in the field of FLW prevention at any point along the entire food supply chain worldwide. Each expert was contacted individually, with a brief explanation of the FOLOU project and an inquiry regarding their availability to collaborate. This collaboration is entirely voluntary on the part of the external expert. The management of this portal is carried out by the advisory board of the FOLOU project, led by the subject matter expert Felicitas Schneider.

- Based on the three online webinars organised to cover specific aspects of FL quantification, such as the definition of food loss in the EU, how to quantify losses at plot, farm, or pond level, and how to extrapolate this information for territorial-level calculations, experts were invited at the end of each session to participate in the review of both the definitional framework and the quantification manual. Moreover, the webinars themselves served as a channel for improvement and

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validation. In addition to carrying out live exercises in data collection and discussing specific aspects, all questions and doubts raised by participants, across their different variables, were compiled into a document. This document was then sent to all attendees, presenting the questions and the responses provided based on the FOLOU project's experience, aiming to achieve validation and consensus among all participants.

- Similarly, in other scientific forums involving experts in the field of FLW, participants were informed at the end of the presentations that, if they were interested in contributing to the review of the definitional framework and or the quantification manual, they could do so by accessing a QR code provided, which directed them to the FOLOU questionnaire required to join the network of experts.
- Finally, consideration was also given to all those experts in the field who independently contacted the FOLOU project and expressed their interest and availability to contribute to the review of both the quantification manual and the definitional framework.

The approach to obtain feedback from all external experts on the FLQM was as follows:

a. The draft of the quantification manual was sent to them in Word or a similar format, making it easy for them to provide suggestions or add comments directly on the text.

b. Once the document was sent, the best approach for addressing questions and obtaining feedback was agreed upon, whether through a video meeting, general comments via email, or by sending back the document with comments and suggestions. In practice, this was usually done by receiving the annotated documents.

c. Once their ideas and comments were received, a follow-up email was sent. If the feedback came in the form of a document, an effort was made to address all comments, indicating whether the suggestion or clarification was accepted. In cases where there was partial or complete disagreement, the reasons were provided to foster a dialogue with the external reviewer, offering the opportunity for them to respond and present further arguments. Through this exchange, the goal was to build a common consensus between both parties. In the case of video calls, this process of dialogue and consensus-building took place directly during the session, unless additional time was needed to review or study specific aspects. In such cases, agreements could be finalised through a follow-up session or via email responses.

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C.3. Development of the second draft of the manual

The review of the first draft resulted in the development of the second draft of the quantification manual by November 2024.

The second draft followed a very similar process to the previous one, first being circulated internally among all FOLOU partners and then shared with the network of experts, which had grown to 117 members. To facilitate the process of a second review, the text was marked to indicate which content was new and which originated from the first version.

The second draft has been refined based on the experience continuously gained from WPs 1, 2, and 3, as well as from the various FOLOU case studies. Naturally, new articles and papers identified during this process were also considered in this validation and improvement effort.

For instance, the work carried out under WP2 should be highlighted, where three different categories of drivers were established: behavioural, environmental, and societal. Within these, various drivers associated with each category were identified as contributing factors to the generation of FL. This classification of drivers is the one that has been incorporated into the manual itself, both for the perceptual and onsite approaches (see Annex 8.1 and 8.2).

A new channel for improvement and validation during this period was through the Twinning Regions, a series of regions interested in understanding and adapting some of the results obtained by the FOLOU project. Within these regions, the majority sought a deeper understanding of the FL quantification methodology. This process led to both group and individual sessions to address their specific needs, as some of them were planning to implement FL measurement processes in their own territories. This also included collecting from them both, the adaptations required for their measurement processes and their subsequent experience.

C.4. Development of the final version

This entire process culminated in the Food Loss Quantification Manual, which, as demonstrated, is intended to be grounded in scientific evidence, the experience of expert organisations in the field (including contributions throughout the manual's development from 24 international experts), FOLOU's own experience, and consensus with all partners and participating external experts.

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1 WHAT? A standard definition for Food Loss

The objective of the chapter is for the reader to understand what is considered food loss and what is not, so that there is a common framework when carrying out the quantification. A concise summary of the **Food Loss Definitional Framework (FLDF) from the FOLOU project** is presented. For more detailed information, please refer to the complete FLDF document (forthcoming on CORA).

Target audience: public administration, researchers, agrifood companies, farmers, livestock breeders, and companies involved in fishing/aquaculture.

1.1 Food loss definition and its boundaries. General context

As stated in the Food Loss Definitional Framework (FLDF), there are currently disparities regarding what constitutes FL with no agreed upon definition within the European Union (EU). In fact, the Delegated Decision 2019/1597 only considers the measurement of FW throughout the entire agri-food chain, starting from post- harvest stage and therefore excluding losses.

One of the main reasons for the absence of food loss in the mandatory quantification is found in the definition of "food" itself, which excludes live animals unless they are prepared for placing on the market for human consumption and plants prior to harvesting. For this reason, two stages of the agri-food chain can already be identified as excluded from the quantification processes for the EU: the pre-harvest and harvesting phases.

However, not all post-harvest processes have been included under the term "food waste" either. This has been motivated by Directive 2008/98/EC on waste [3]:

"*The following shall be excluded from the scope of this Directive:*

(...)

faecal matter, if not covered by paragraph 2(b), straw and other natural non-hazardous agricultural or forestry material used in farming, forestry or for the production of energy from such biomass through processes or methods which do not harm the environment or endanger human health".

Therefore, there are still a few "grey areas" to be clearly identified and agreed on within the post-harvest stage, to determine what would be considered "food waste", "by-product", and "food loss", in line with EU regulations. The Food Loss Definitional Framework (FLDF) has been created as a starting point to build consensus and clarity around these definitions (Figure 3). Thus, to encompass all these circumstances and nuances in a general definition for food loss, the following text is proposed:

Food loss is any harvest-mature plant, animal or living being 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.

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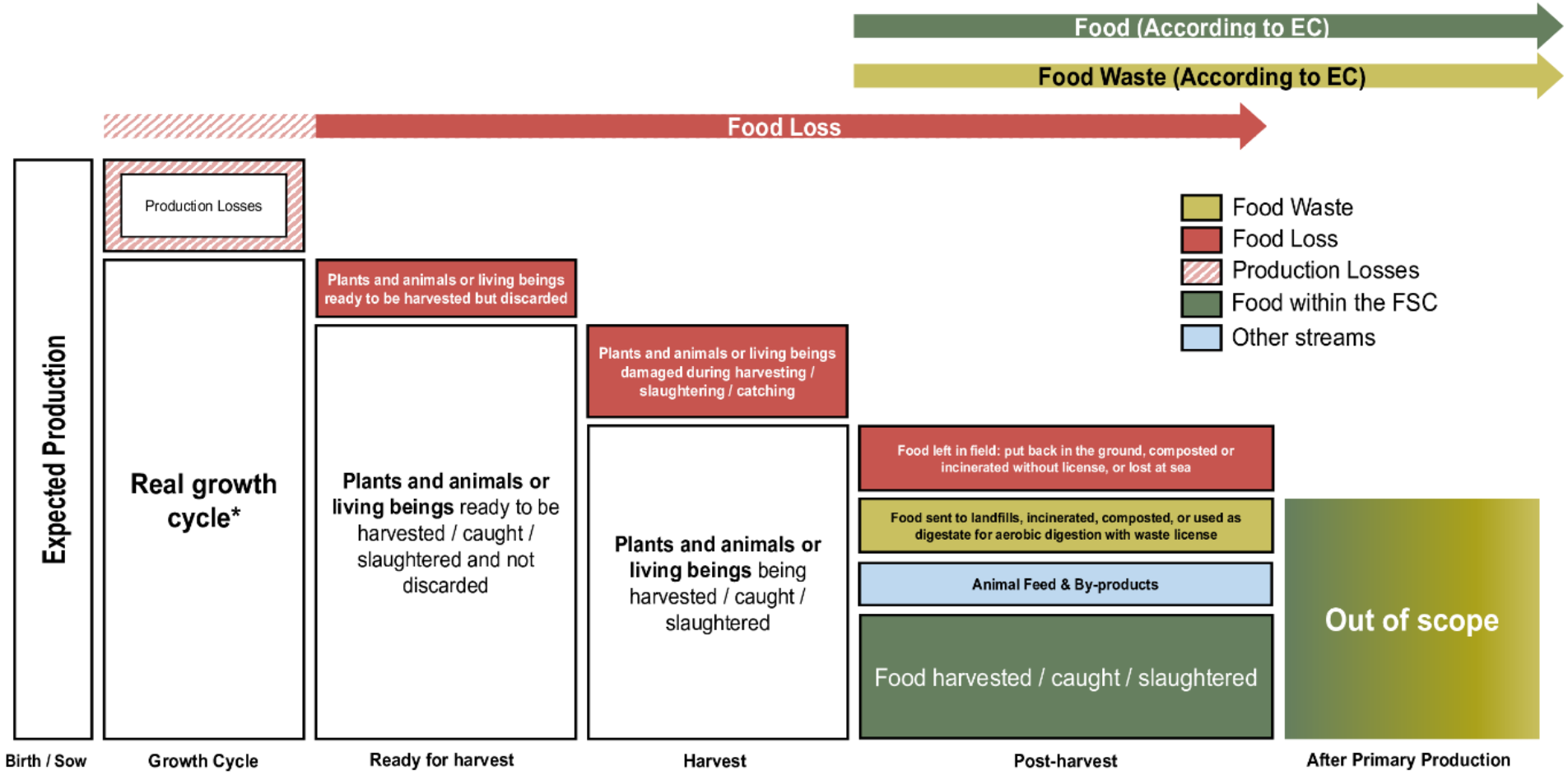

Figure 3. The FOLOU Food Loss Definitional Framework. Source: authors' own elaboration

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Figure 4 highlights the main boundaries of the FOLOU FLDF of “food loss”. Parameters included within the term "food loss", are marked in green (✓); those not included as “food loss” are marked in red (✗); and those categorised as "partially included", in orange ([≈]). This last category includes the case of meat, where the slaughtering phase (harvesting) is only partially included.

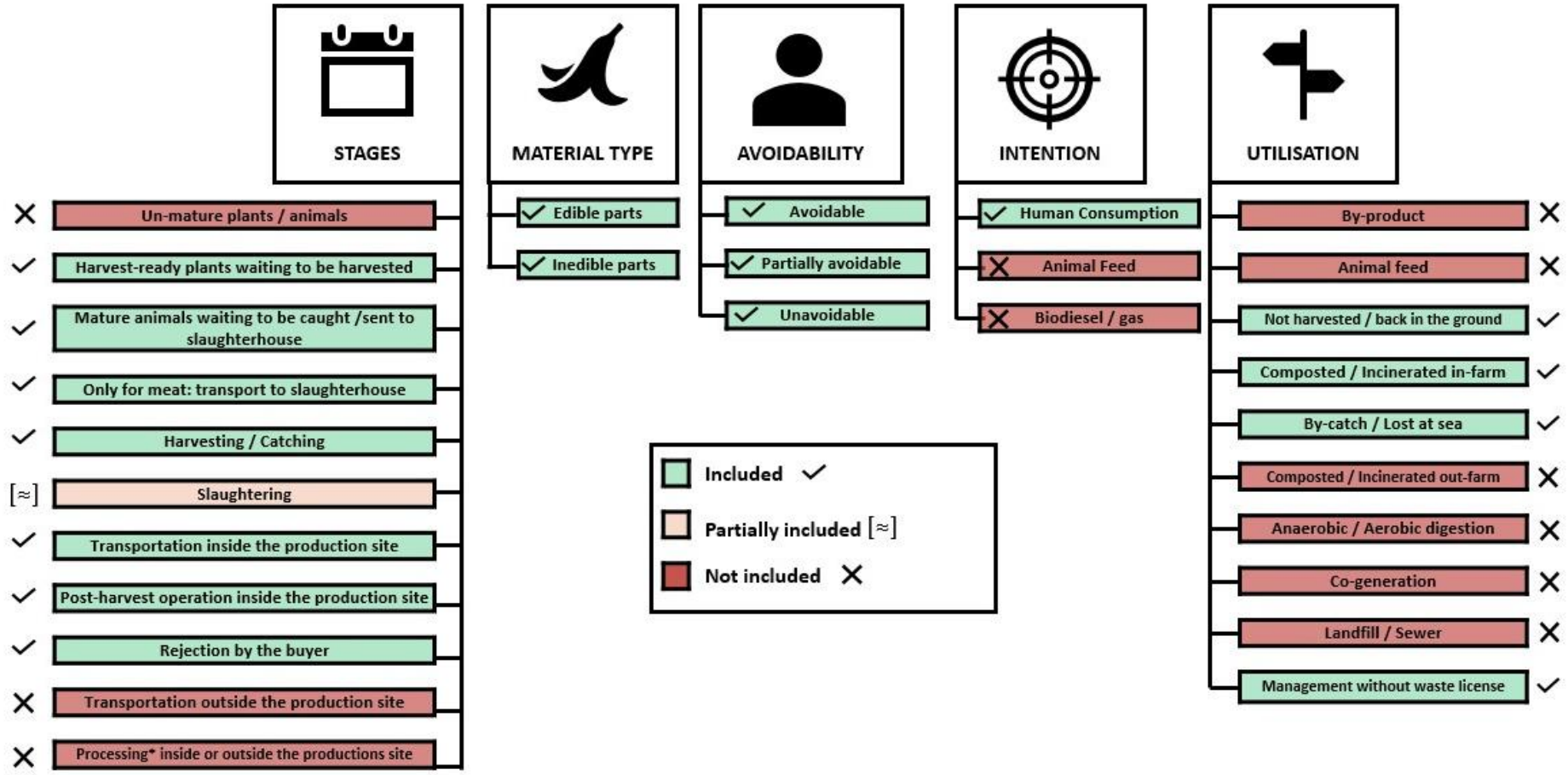

Figure 4. Main boundaries of the FOLOU Food Loss Definitional Framework. Stages in green indicate when FL is considered (✓), in yellow when it is only partially included ([≈]), and in red when it is not considered (✗). Source: authors' own elaboration, inspired by the structure of Figure 6.1 in the FLW Standard [2].

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1.1.1 Stages

The FLDF breaks down losses into three key stages:

1. **Pre-harvest Stage:** This stage begins when a product is "ready for harvest/slaughter/catching," based on criteria like edibility, market standards, and market dynamics. Losses occurring from this point until the actual harvest are considered FL. Discards that happen *before* this point (e.g., unripe crops damaged by weather or pests) are excluded from FL and are instead defined as "*production losses*", a separate concept important for assessing the agri-food system's overall efficiency.
2. **Harvesting Stage:** This stage covers the actual process of harvesting, slaughtering, or catching. Losses here are caused by technical issues (mechanical damage, spillage) or operational constraints (e.g., harvesting at suboptimal times to meet market demands). It also includes food left unharvested because it doesn't meet marketing standards, or because market prices do not cover the costs of harvesting and selling. Losses from grading or storage are not included here, as they belong to the next stage.
3. **Post-harvest Stage:** This is the final phase of primary production, starting after harvest and ending before manufacturing. It is the only stage where "food loss" and "food waste" can coexist. FL here occurs during on-farm transport, storage, and sorting/grading. Once food leaves the production site, any discards are classified as FW. Food returned to the farm by a buyer (e.g., for quality reasons) is also considered a FL. An example to differentiate both concepts could be the following: several boxes of tomatoes have been harvested and kept for some time in the farm warehouse while awaiting transport. However, due to an error in the warehouse itself, they have deteriorated. Thus, if those tomatoes are taken and thrown onto the ground on the farm, they would be considered food losses, whereas if those boxes are collected and managed as waste by a licensed company, to be recovered for energy purposes, they would be considered food waste.

1.1.2 Material type

Consistent with the EU ‘food waste’ definition from the Delegated Decision 2019/1597 mentioned above, both edible and inedible parts of food will be considered as FL. However, in order to understand the optimal use given, in this Manual, it is advisable to determine whether FL consist solely of inedible parts (e.g., orange peel), only edible parts (e.g., the edible portion of the orange), or a combination of both edible and inedible parts (e.g., the entire orange). Commonly, in the diagnosis of FLW, emphasis is often placed on monitoring and reducing the edible parts of food, sometimes categorising them as avoidable, while the inedible parts are considered inevitable. However, in the current context of the Circular Economy, there is also a need to reconsider the uses and destinations for inedible parts, as they can be valuable inputs for creating new resources, rather than ending up as waste sent to landfills. Moreover, this separation and identification of only the edible parts adds a further layer of complexity to measurement, as it includes determining which parts are considered “edible” and “inedible” for each item, since these classifications may at times involve cultural factors that add complexity to the distinction (e.g., consumer preferences for the use of peels and stems in some cuisines) [4–6].

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1.1.3 Avoidability

Avoidable food loss refers to food that was suitable for human consumption at some point prior to disposal, but gets discarded as it is no longer wanted or it has passed its best condition [7,8].

According to the FLDF, both avoidable and unavoidable FL will be considered in this project. Despite its widespread use, the JRC [9] has already shown that there appears to be considerable heterogeneity in the interpretation of "avoidable" and "unavoidable" food waste across different EU food waste studies. In any case, in line with other quantification manuals and studies [2,10] that do make these categorizations, both avoidable and unavoidable food loss will be considered in this project. However, informed by research on FL drivers (Deliverable D2.2), a distinction between these two groups will be made, whenever possible, to provide information on potential actions.

1.1.4 Intention

Another aspect that is detailed in the definition of food proposed by EU regulations [11] is that only food intended for human consumption (initially or at some point, as declared by the producer) will be considered as FL.

1.1.5 Utilisation-final destination

The category "utilisation-final destination" represents the real end-use of the product. Food that leaves the food supply chain during the post-harvest stage will be considered as FL or FW, according to its utilisation. Food that ends as by-product is not considered as waste nor loss. Accordingly, animal feed is not considered as FL nor FW, as it is reverted to the Food Supply Chain. However, for the purpose of this project, we try to quantify it to generate additional valuable data and to align with the paradigm of the Circular Economy. Thus, animal feed can be regarded as a suboptimal use of food, in line with the food waste hierarchy Click or tap here to enter text., and should therefore be quantified and monitored, even if under the umbrella of the "animal feed" destination.

For a further explanation of the different boundaries identified for the concept of FL, as well as the various parameters that have been included or excluded from this term, it is recommended to refer to the FLDF (forthcoming on CORA).

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2 WHERE? Measuring food loss within a territory

This chapter explains the importance of defining where to measure food loss within a territory and how to approach this task. It guides the reader in planning a territorial diagnosis of food loss by 1) identifying the main economic activities that may generate food loss, and 2) prioritising quantification in the areas of the territory where these activities are most concentrated.

Target audience: public administration and researchers.

2.1 The importance of defining where to measure

When considering where to quantify FL along the agri-food chain, this not only refers to specific food supply chain stages or stakeholders (entities or companies) where this issue may arise, but also to the specific sectors or subsectors within primary production that need to be measured.

Similar challenges have been described for the entire agri-food chain, encompassing both FL and FW. The Joint Research Centre of the European Commission conducted an analysis of major studies on FLW, primarily at the national level within the European Union [9]. It was found that although many studies quantified similar stages (primary production, manufacturing, distribution, and/or consumption), the final figures identified by studies could not be compared.

One reason for this was the diversity of concepts used to measure FLW [10–19], including those originating from the FAO, the European Union, or even unique definitions proposed by individual territories. This issue highlights the importance of establishing consensus-based definitions and concepts across all territories within the European Union, thus responding in a similar manner to the "What?" question in the previous chapter.

Additionally, there was another parameter that hindered the comparability of results between studies: while many cases analysed the same stages of the food chain, the sectors or subsectors included within these chain stages varied. For example, imagine multiple reports quantifying FLW in different EU countries. These countries examined various chain stages, including a stage where all reports coincided and provided measurement figures: the consumption phase. This could suggest that if it was a common and consistent stage across all studies, the results could be compared. However, upon analysing the sectors and subsectors measured within the consumption phase, some studies included households and hospitality, others included schools, hotels, and households, and others, for example, focused solely on schools. Therefore, although they all seemed to measure the same reality, a closer look at the sectors and subsectors analysed revealed different realities, meaning that even though the object of study was defined in the same way (in this case, "consumption phase"), they were different objects.

The same example of the consumption phase can be applied to primary production, as there are no clear criteria regarding which economic activities or specific crop typologies should be identified in advance for diagnosing the problem of losses in a territory.

To minimise these errors, the Delegated Decision 2019/1597 has recommended criteria for identifying the sectors and subsectors to consider when measuring FW along the agri-food chain. This methodology utilises an internationally agreed and common code for the entire European Union: the statistical classification of economic activities in the European Community (NACE codes) [12].

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The following sections explain the recommendation proposed by the Delegated Decision 2019/1597, aiming to respond the "Where?" question. They also present a methodological proposal from FOLOU to improve and apply it to the case of FL in the European Union.

2.2 Introduction to the methodology recommended by the Delegated Decision

As a general guideline, any location where food or raw material of food can be produced/managed, from being ready to be harvested/slaughtered/caught to processing, will be considered a potential generator of food loss (PGFL).

To identify the potential points of FW generation, the Delegated Decision [1] proposes the use of an internationally agreed-upon coding system, such as the statistical classification of economic activities in the European Community (NACE Code). Therefore, it is recommended to use this same coding system for identifying locations of PGFL.

In the specific case of primary production, the Delegated Decision 2019/1597 identifies Divisions 1 (Crop and animal production, hunting and related service activities) and 3 (Fishing and aquaculture) as the economic activities to be quantified (Figure 5). The same criterion could be used for FL.

ANNEX I

Attribution of food waste to the different stages of the food supply chain

		Activity which generates waste		
Stages of the food supply chain	Relevant item in Waste Statistics (1) which include given stage of food supply chain	Relevant NACE Rev. 2 code		Description
Primary production	Part of Item 1	Section A		Agriculture, forestry and fishing
			Division 01	*Crop and animal production, hunting and related service activities*
			Division 03	*Fishing and aquaculture*

Figure 5. Attribution of FW to the primary production stage by the Delegated Decision. Source: Commission Delegated Decision (EU) 2019/1597.

To analyse the specific meanings and resulting implications of these measurement recommendations for Divisions 1 and 3, it is necessary to first understand the general structure of the NACE coding system.

Figure 6 provides an overview of the general structure of NACE codes, illustrating a hierarchical structure from less to more specificity and breakdown. The higher-level categories (sections) are the most general, as seen in the example of Section A. On the other hand, NACE classes are more specific in relation to specific economic activities, as can be observed in the example of Class 01.11.

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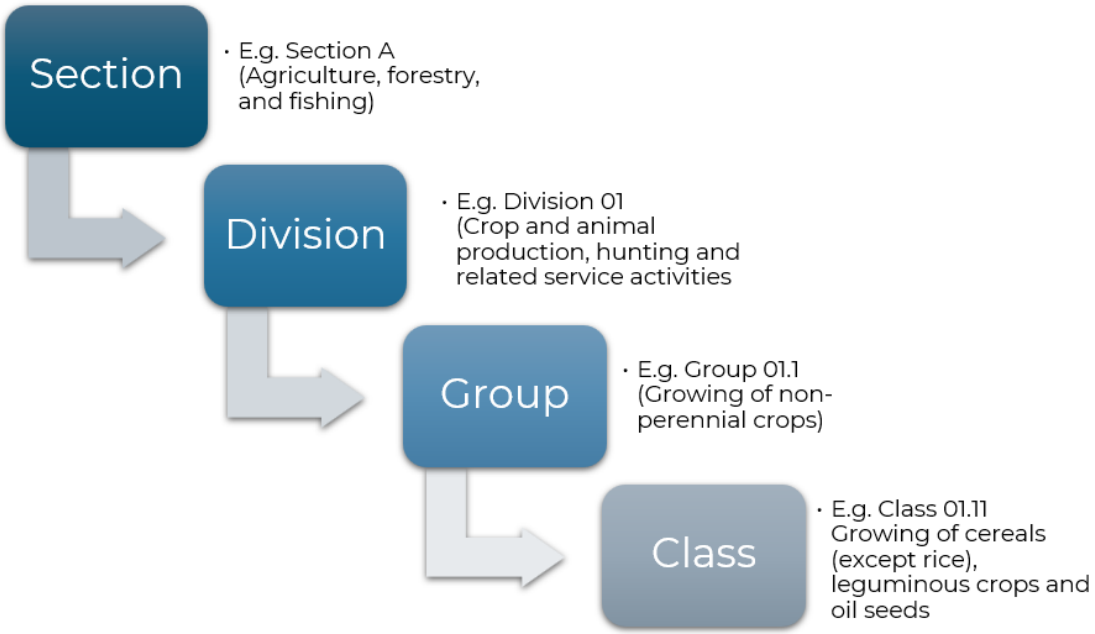

Figure 6. General structure of NACE Codes. Source: authors' own elaboration

The Delegated Decision 2019/1597 proposes the main categories for identifying the sectors and subsectors to be analysed for measuring FW in the primary sector as Divisions 01 (Crop and animal production, hunting and related service activities) and 03 (Fishing and aquaculture).Table 1 shows the exact meaning of measuring Divisions 01 and 03, displaying all the economic activities included within these NACE categories.

Table 1 and Table 2 break down these activities by both NACE Group and NACE Class. Therefore, to analyse FW in primary production according to the Delegated Decision 2019/1597, it is necessary to quantify all the economic activities that fall under both NACE Division 01 and 03.

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Table 1. Economic activities included in NACE Divisions 01 and 03 (Part A)

Division Code	Group Code	Class Code	Class Name
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
		01.12	Growing of rice
		01.13	Growing of vegetables and melons, roots and tubers
		01.14	Growing of sugar cane
		01.15	Growing of tobacco
		01.16	Growing of fibre crops
		01.19	Growing of other non-perennial crops
	01.2		Growing of perennial crops
		01.21	Growing of grapes
		01.22	Growing of tropical and subtropical fruits
		01.23	Growing of citrus fruits
		01.24	Growing of pome fruits and stone fruits
		01.25	Growing of other tree and bush fruits and nuts
		01.26	Growing of oleaginous fruits
		01.27	Growing of beverage crops
		01.28	Growing of spices, aromatic, drug and pharmaceutical crops
		01.29	Growing of other perennial crops
	01.3		Plant propagation
		01.30	Plant propagation
	01.4		Animal production
		01.41	Raising of dairy cattle
		01.42	Raising of other cattle and buffaloes
		01.43	Raising of horses and other equines
		01.44	Raising of camels and camelids

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Table 2. Economic activities included in NACE Divisions 01 and 03 (Part B)

Division Code	Group Code	Class Code	Class Name
SECTION A — AGRICULTURE, FORESTRYAND FISHING			
01			Crop and animal production, hunting and related service activities
	01.4		Animal production
		01.45	Raising of sheep and goats
		01.46	Raising of swine/pigs
		01.47	Raising of poultry
		01.49	Raising of other animals
	01.5		Mixed farming
		01.50	Mixed farming
	01.6		Support activities to agriculture and post-harvest crop activities
		01.61	Support activities for crop production
		01.62	Support activities for animal production
		01.63	Post-harvest crop activities
		01.64	Seed processing for propagation
	01.7		Hunting, trapping and related service activities
		01.70	Hunting, trapping and related service activities
03			Fishing and aquaculture
	03.1		Fishing
		03.11	Marine fishing
		03.12	Freshwater fishing
	03.2		Aquaculture
		03.21	Marine aquaculture
		03.22	Freshwater aquaculture

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2.3 FOLOU's proposal for improving the identification of potential points of food loss generation

2.3.1 Improvements through the use of NACE codes

From the FOLOU project's perspective, the general criterion of the Delegated Decision 2019/1597, described in the previous section, is considered necessary for identifying potential points of FL generation, not just for FW as currently recommended.

In the specific case of primary production, Table 1 identified all economic activities within Divisions 01 and 03. It is worth considering whether all the detailed listings, broken down by NACE Groups and Classes, are related to the production and/or management of food, and thus susceptible to being potential sources of food loss or waste.

To answer this question, it is necessary to move away from the discussion about the definition of FW in relation to stages within primary production, where only harvested items are currently considered as food. Instead, focus should be placed on the types of products produced and/or managed within each NACE Class, which are further detailed in the literature produced by EUROSTAT[13].

By meticulously analysing each of these economic activities according to NACE Classes, it becomes evident that there are activities unrelated to food management and/or production. Therefore, they should be excluded from being identified as activities capable of generating food loss or waste. Examples include Class 01.15 (Growing of tobacco), 01.16 (Growing of fibre crops), and 01.30 (Plant propagation).

For this reason, FOLOU aims to contribute methodological improvements to the existing approach established by the Delegated Decision 2019/1597. In this case, the focus is on using the highest level of disaggregation and specificity within the NACE system: NACE Classes[14]. Therefore, this initial proposal is made within Divisions 01 and 03, establishing three main categories for different NACE Classes:

- **High Priority (HP):** Economic activity mainly linked to the production and/or management of food, and therefore, capable of generating FLW. These activities require quantification to diagnose the amount of FLW in a territory.
- **Low Priority (LP):** Economic activity partially linked to the production and/or management of food. This partial linkage primarily occurs because certain NACE Classes encompass various economic activities, some related to food production and/or management, while others are not. An example of this is Class 01.49 (Raising of other animals), which includes activities related to human food production such as honey production, as well as the raising and breeding of pet animals.

  Another possibility is an activity that rarely has any connection to human food consumption, but in exceptional and specific cases it may occur. An example is Class 01.44 (Raising of camels and camelids) for camel breeding for milk production. Therefore, the quantification of these economic activities for assessing FLW does not appear to be crucial at the outset and would fall into a lower priority level compared to those classified as high priority.
- **Not Susceptible to Generate Food Loss or Waste (NA):** Economic activity with no connection to the production and/or management of food and therefore, should be excluded from measuring FLW.

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Table 3 and Table 4 present the final list of economic activities that should be quantified for the analysis of FL in primary production, within the recommended Divisions 01 and 03 by the Delegated Decision 2019/1597.

Table 3. Economic activities included in Divisions 01 and 03 of the NACE codes with the potential to generate FL according to FOLOU's methodology (Part A)

Division Code	Group Code	Class Code	Class Name	FOLOU proposal
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
	01.4		Animal production	
		01.41	Raising of dairy cattle	HP

HP: High priority of being measured.

LP: Low priority of being measured.

NA: Not applicable

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Table 4. Economic activities included in Divisions 01 and 03 of the NACE codes with the potential to generate FL according to FOLOU's methodology (Part B)

Division Code	Group Code	Class Code	Class Name	FOLOU proposal
	01.4		Animal production	
		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

It can be observed that out of the 35 economic activities considered in Divisions 01 and 03, the methodology proposed by FOLOU identifies 23 as clearly deserving quantification (HP) in a territory to analyse the loss. However, 3 activities considered theoretically capable of generating some form of loss, do not appear to be substantial activities for the

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measurement of this issue (LP). Finally, 9 economic activities are excluded from this measurement (NA).

Thus, this methodological approach aims to emphasise a fundamental aspect of measuring loss and FW in primary production: the process of extrapolating results. In this way, it avoids measuring primary production as if it were uniform compartments within Divisions 01 and 03. Instead, it recognises that within these divisions there are economic activities of very different nature. Therefore, it is advisable to conduct extrapolation processes only for economic activities belonging to the same more detailed NACE "Classes", rather than using more general categories that integrate sectors and subsectors that are significantly different from each other. The problems associated with these sectors are both unlikely to be comparable or able to be extrapolated beyond the same group.

2.3.2 Improvement using Classification of Products by Activity (CPA)

Another methodological improvement proposed by FOLOU is to provide further specificity to NACE categories. This new improvement is guided by the idea that "we cannot compare apples and pears". Applying this concept to the NACE coding, apples and pears fall under the same NACE Class: 01.24 (Growing of pome fruits and stone fruits).

Therefore, FOLOU provides a methodology that enables a more detailed definition of crop typologies by using an internationally agreed classification system linked to the NACE codes: the Classification of Products by Activity (CPA). This classification system consists of 5 or 6 numerical codes, where the first four belong to the specific NACE Class for the produced food, and the last two identify each specific type of food. In this way, apples are coded as 01.24.10 and pears as 01.24.21. This way they are placed in separate groups and prevent the aggregation of loss quantities between pears and apples[3].

By utilising this approach, the extrapolation processes become more complex due to the increased number of groups based on specific crop typologies. However, FOLOU considers it to be a more precise approach for diagnosing the issue of FL in a territory. The level of precision can vary depending on the use of 5 or 6-digit CPA codes.

Table 5 illustrates the differences between the first improvement, using exclusively NACE Classes, and the use of 5 or 6-digit CPA codes. With a single NACE Class, it is possible to differentiate between various products based on different detail levels. As shown in Table 5, for the specific case of NACE Class 01.11 (Growing of cereals (except rice), leguminous crops and oil seeds), this Class can be disaggregated into 9 or 29 different food product categories, depending on the 5 or 6-digit CPA coding.

It should be noted that within these codes, some may not be linked to food, such as 01.11.84 (Cotton seed), and therefore should also be excluded from the quantification processes of FL in a territory.

[3] EUROSTAT. Classification of Products by Activity (CPA).

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Table 5. Comparison of data breakdown level according to NACE Class or CPA level

NACE Classes approach	CPA approach	CPA approach 2
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 Maise	01.11.20 Maise
	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 Chick peas, 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.

The proposed methodological improvements, both for the 5-digit CPA approach where apples and pears are already differentiated, as well as the 6-digit approach, have been divided according to the main types of food commodities.

Thanks to these lists, whether through NACE Classes or 5 or 6-digit CPA coding, a decisive first step can be taken in quantifying FL in a territory by determining which groups will be used for the extrapolation of data (for further information, see Chapter 4).

Another important aspect of using NACE and CPA codes is the possibility of converting them into codes used in regions outside the European Union. One of the international coding systems that may be particularly relevant for converting NACE codes is the International Standard Industrial Classification of All Economic Activities (ISIC)[15]. These codes are very similar in structure to NACE, as shown in Table 6, and in some cases, they are completely identical. Table 5 shows the comparison for the same NACE or ISIC group (011), where it can be observed that not only is there the same number of Classes, but they are also completely identical in both their numerical code and their associated name.

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Table 6. Comparison of NACE and ISIC Codes by Class. Example of Classes included in Group 011: Crop and Animal Production, Hunting, and Related Service Activities.

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

In the case of the CPA, the Central Product Classification (CPC)[4] should be highlighted as one of the primary codes for converting them to an international coding system. In this case, as can be seen in Table 7, conversions are possible, although they are not as identical as in the previous case of NACE and ISIC. In this instance, the 6-digit subcategory of the CPC is considered the most convenient for conversion. CPC codes can vary between 5 and 6 digits, depending on the specificity of the food item. It can be observed that some codes are very similar, such as in the case of maise, while others have different codifications. Additionally, some CPA categories are more detailed than those in CPC (e.g. wheat) or vice versa. In the latter case, the CPA code "01.11.49" is broken down into five different categories for the CPC.

Table 7. 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	Maise	0112	Maise (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.

For all these reasons, in response to the question "Where to measure?", the use of this type of international coding is considered a promising approach. These codes are utilised in specific regions, such as the EU, providing a common framework across all its territories. Moreover, they can be converted to other coding systems used in regions outside the EU, thereby facilitating synergies and comparability of results across different studies.

[4] The Central Product Classification (CPC).

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2.4 Designing a territorial diagnosis of food loss

Having reviewed FOLOU's proposals to improve the identification of potential FL generation points at the territorial level, the following paragraph outlines the steps to be followed to select the areas of the territory to be studied.

2.4.1 Identifying key economic activities and areas for measuring food loss at territorial level

It is necessary for the entity responsible for measuring FL in a territory to collect information from the main statistical agencies where the measurement processes will take place. The most relevant data to collect include:

- Information on the number of farms in the territory, categorised by 4-digit NACE codes, as listed in Table 3, particularly the codes classified as "high priority (HP)". If the measurement work is being conducted at a regional or state level, it is advisable to have farm information disaggregated by municipalities, regions, or provinces. The importance of this data will be explained in the following sections of the manual.
- Information on the extent of Utilised Agricultural Area (UAA) in the study area.
- Data on the production volume of each type of crop in the study area.
- Optionally, and due to the difficulty of obtaining this type of information, the collection of 4-digit NACE information will be further disaggregated according to the Classification of Products by Activity (CPA).

In general, and ideally, the highest level of reliability in measuring losses in a territory would involve quantifying the entire area, according to crop typologies, by weighing, covering the entire growing season, over more than one year. However, recognising the limitations of available resources, different solutions will be addressed to achieve the highest level of reliability despite budgetary and temporal constraints. It is important to note that these solutions never reach the same level of reliability as the initial/ideal proposal.

With this baseline information, decision-making processes can be carried out to identify priorities for quantifying losses, especially in two areas:

- Which economic activities within primary production and which types of crops/livestock/fisheries are most relevant in the territory, and thus of higher priority in determining the measurement processes for FL[5].
- Which areas of the study territory have a higher concentration of these economic activities/crop types to facilitate efficient measurement of the aforementioned FL.

This prioritisation can be better understood through an example:

Example to determine measurement priorities based on economic activities and product typology in a territory (Region X)

[5] It is important to note that at this stage, providing a minimum percentage of products that can serve as the starting point for the measurement process is not possible, as this methodology is in its early stages. However, we recommend considering not only production quantity, but also market value — or, for instance, whether a product is particularly relevant for a territory.

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Consider a European region, Region X, where the measurement of FL is being pursued. By gathering information, it has been determined that most of the agricultural land, around 87% of the total, is dedicated to 7 main crops (Table 8). Therefore, it has been agreed that these 7 crops will be included in the process of measuring FL. It is important to note that in this case, Region X did not have specific data based on CPA. However, they did have data based on crop typology, so the reverse approach was taken: those crop typologies were subsequently matched with their corresponding CPA codes.

Table 8. Main crops in Region X in 2023. Text in blue denotes an example using fictitious data

NACE Classes	**Food commodity (CPA)**	**Total cultivated hectares (ha)**	**Total annual production** (tonnes in live weight)
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

From the livestock perspective (Figure 7) there are 3 key sectors based on the number of farms located in Region X, with poultry farming accounting for almost half of the farms. These sectors have been further broken down according to the types of products generated by economic activity (Table 9), where it can be observed that there are 3 main product types that will be the focus of measurement and analysis of losses in Region X.

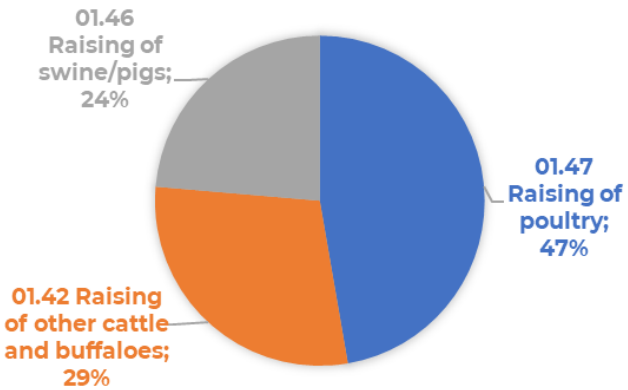

Figure 7. Livestock farms located in Region X, in percentages. Source: authors' own elaboration

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Table 9. Main livestock farms in Region X in 2023. Text in blue denotes an example using fictitious data

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

Regarding aquaculture and fishing, three main economic activities have been identified based on the NACE Classes (Figure 8), within which there are six different food products (Table 10). Unlike agriculture and livestock, the CPA coding for aquaculture and fishing is not as specific so these product categories have been named without the possibility of incorporating an internationally agreed-upon coding.

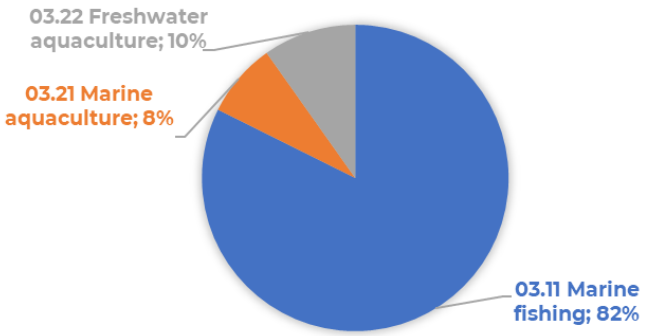

Figure 8. Number of companies/vessels in the fishing and aquaculture sector located in Region X, in percentages. Source: authors' own elaboration

Table 10. Companies/vessels in the fishing and aquaculture sector of Region X in 2023. Text in blue denotes an example using fictitious data

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

Using this method, a total of 16 main food typologies has been identified to diagnose food loss in Region X. Among them, 7 are found in agriculture, 3 in livestock farming, and 6 in fishing and aquaculture.

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2.4.2 Identifying which areas of the study territory have a higher concentration of these economic activities/crop typologies

Once the main economic activities and primary product typologies generated in Region X have been identified, measurements should be carried out for each of these product typologies. For example, separate calculations will be necessary for rice, wheat, chickens, and trout. As discussed in the previous chapter, each of these groups is distinct enough to warrant separate calculations to establish a valid FL index.

In this section, we will focus on establishing priorities when determining the plots where FL quantification processes will be conducted in Region X. In a territory of considerable size, such as the national or regional level, or territorial scales similar to those equivalents to the European Union, according to the common classification of territorial units for statistics (NUTS), to the NUTS 1 and 2[16], there is often high heterogeneity in the production of different food typologies that are being studied. Establishing random measurement areas on such a large scale is not always cost-effective or feasible. Instead, it is more efficient to cover the smallest possible territory with the highest concentration of the economic activity being measured.

For example, if the aim is to quantify wheat production losses in Region X, we suggest first gathering information broken down by lower territorial scales, such as districts or counties, as for the equivalent of NUTS 3. This information could be obtained as follows:

- Annual wheat production by county (tons)
- Hectares (ha) of wheat cultivated by county
- Number of wheat farms by county

Ideally, all three sets of data should be obtained. Priorities can be clearly established based on the three parameters, with emphasis given to counties with higher annual wheat production volumes and cultivated hectares. In this manner, it would even be possible to calculate the sampling area based on cultivated hectares in each county relative to the total. This would consider the necessary statistical variables, such as the margin of error and confidence level.

One of the most widely used and rigorous methods for quantifying FL involves establishing different measurement areas randomly throughout the region (NUTS 2), covering the entire calculated sampling area.

However, there are alternative sampling strategies that may be more suitable depending on specific cases/examples, some of which are described in the manual. However, as previously mentioned, due to budgetary and/or time limitations, it is not feasible to conduct measurements throughout the entire region. Therefore, it would be helpful to prioritise measurement areas across the region. In these cases, information about the cultivated area by provinces (NUTS 3) or by counties (sub-NUTS 3, aggregation of LAU 2 municipalities[6]) becomes especially important, as it allows us to establish the same sampling area as before but within a much more limited territorial space.

Example to determine which areas of the territory (Region X) have a higher concentration of these economic activities/crop typologies

Using the example of Region X and the wheat cultivation area in each county (Figure 9), we can order them in a way that calculates the percentage of the cultivated area in each county

[6] Local administrative units (LAU)

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(Figure 10). This reveals that more than 50% of the wheat cultivation area in the entire Region X is concentrated in just three counties, namely counties 1, 2, and 9. By focusing efforts on this area, we can obtain the required sample at a lower cost. However, it is important to note that this approach sacrifices some level of result reliability by not collecting samples randomly throughout the region.

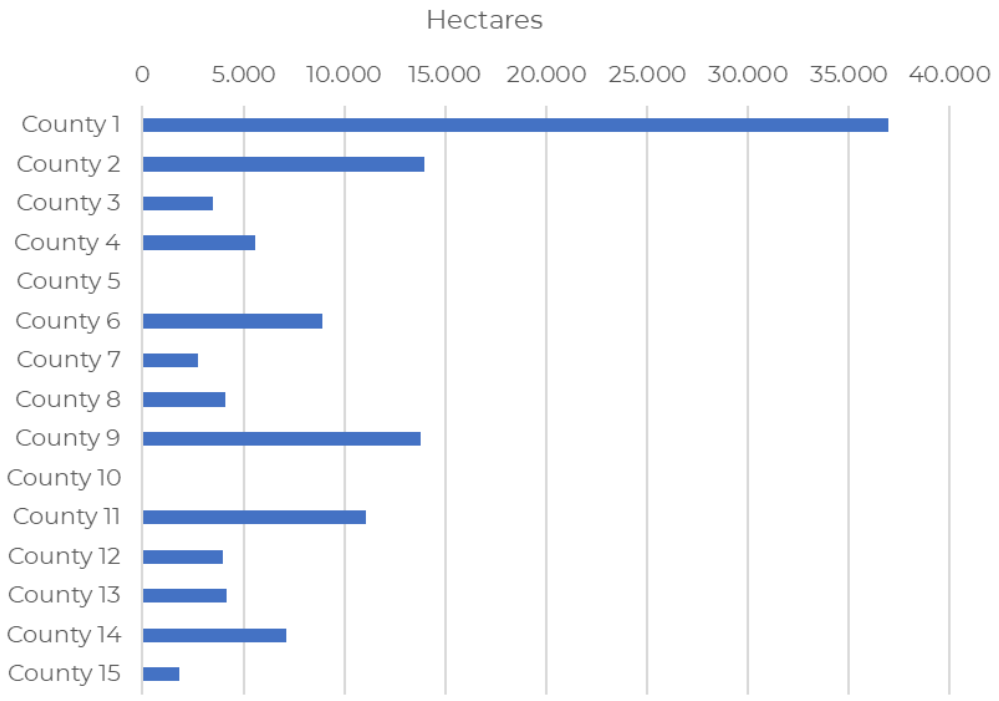

Figure 9. Wheat cultivation area in Region X, by counties and hectares. Source: authors' own elaboration

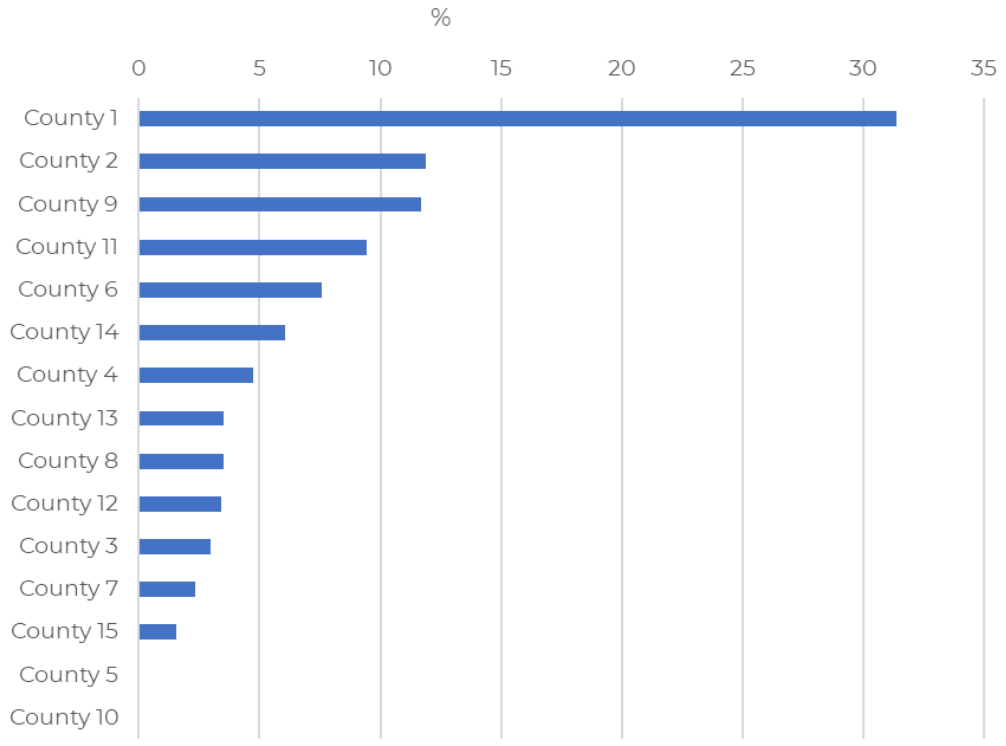

Figure 10. Wheat cultivation area in Region X, by counties and as percentages of the total. Source: authors' own elaboration

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In other cases, there may be not only budget and time limitations but also limitations in the available information, requiring the management of data and establishment of priorities based on the available data.

An example of this could be when, in the case of wheat, there is production and cultivation area data available at the regional level, but no information is available at the county level. Fortunately, at least there is a list of all wheat farms at the regional level. In this scenario, an approximation can be made towards the smallest area of land to be quantified, based on the number of agricultural farms in Region X (Figure 11). These data can also be converted into percentages of the total (Figure 12) to determine the counties with the highest concentration of agricultural farms, specifically for wheat production. It is important to note that, in addition to the mentioned errors in the previous scenario, priorities are being established based on the number of farms. This implies that a higher number of farms indicates greater economic activity. However, it is possible that there may be a very low number of farms for a specific agricultural product but with a large cultivation area, which would not be reflected in these data. Nevertheless, this manual aims to provide approaches towards the best method of measuring losses based on the limitations present in each territory.

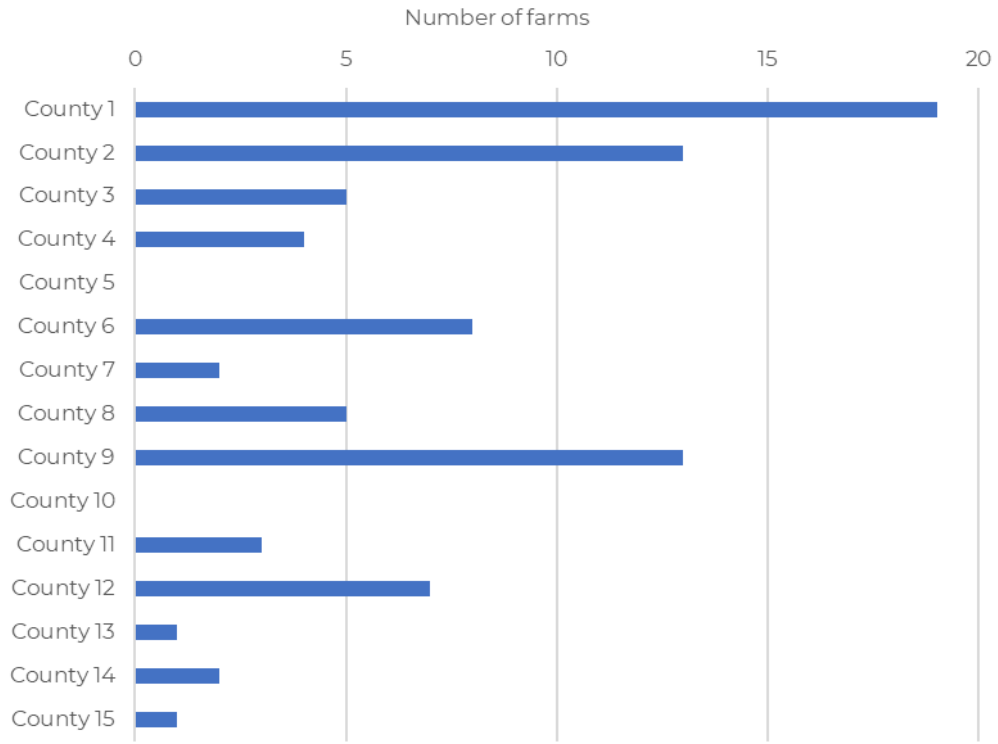

Figure 11. Number of farms producing wheat in Region X, by counties. Source: authors' own elaboration

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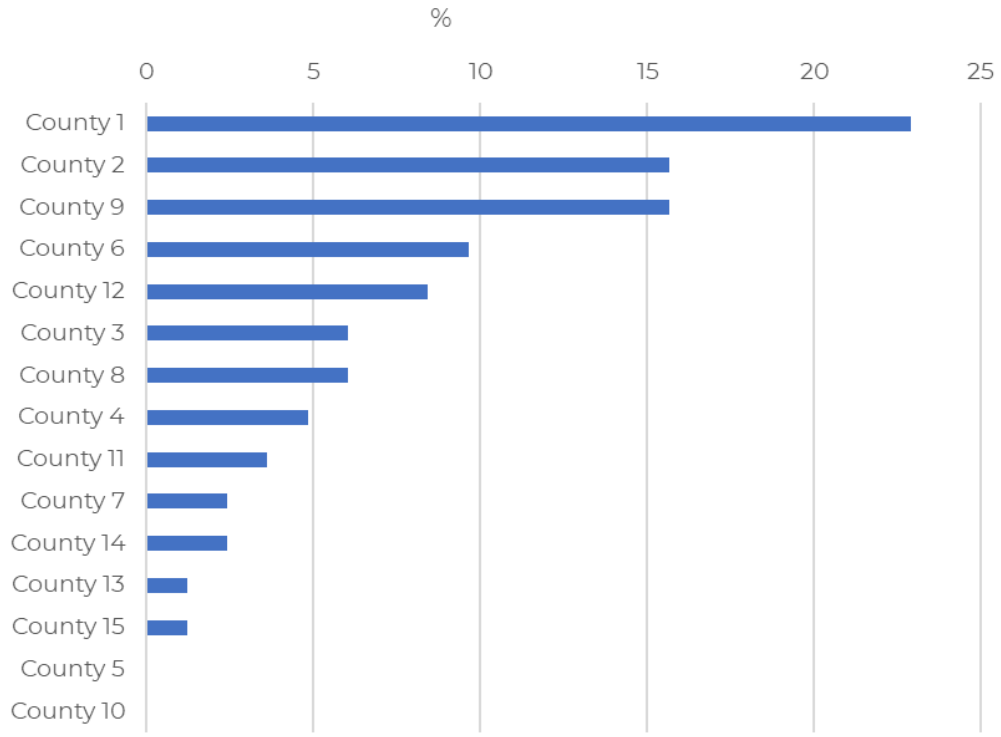

Figure 12. Number of farms producing wheat in Region X, by counties. (Percentages of the total). Source: authors' own elaboration

2.4.3 Identifying farms and plots to be quantified within areas with high concentration of relevant economic activities

Once the sample or necessary land area to quantify and obtain a representative measurement of the issue of FL in a territory has been defined, it will be necessary to establish on-site quantification in different agricultural plots. As outlined in previous section, this is ideally achieved by randomly selecting a series of plots throughout the entire territory. However, if this is not feasible then a portion of land with a high concentration of the economic activity to be diagnosed can be selected.

A recommended option to randomly select plots in a territory is through the use of listings of agricultural farms that may be available, along with their specific NACE classification. These databases usually include additional information to contact the owners of such plots. Another possibility, although less statistically rigorous, is to choose plots with which there have been previous collaborative ties, ensuring cooperation with the processes of measuring FL.

At this point, it is essential to highlight a key factor in measuring FLW: the *engagement process of the stakeholders* in the supply chain to facilitate and enable measurement processes on their farms, plots, and/or businesses.

The importance of this step in ensuring that measurements are actually taken is often overlooked but evidence across Europe has shown that FL measurement efforts cannot succeed without stakeholder engagement. Two studies in the Czech Republic[17,18] found that data collection through questionnaires in the fruit and vegetable production sector was very low over several years, with the main reason being the reluctance of producers to

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share such information. A study in the agricultural and fishing sector in Estonia found that low participation rates in a quantification programme was primarily due to a lack of interest in participating in such initiatives[19].

Therefore, while it is possible to obtain an extensive database on different types of crops in a territory, broken down by NACE or CPA codes, and with contact information for each of these agricultural enterprises, this does not necessarily guarantee success in the process of measuring losses on these farms.

Hence, when planning to measure losses in a specific territory the public administration itself should make efforts to engage with as many stakeholders as possible in quantifying losses. Examples of engagement strategies include:

- Through the contact information available in the databases, having previously identified which farms/plots need to be quantified, reach out to the individuals responsible for these farms/plots to explain the initiative and what is expected of them. In this regard, it is recommended that the owner's efforts and resources be kept to a minimum. One initial possibility could be to contact and work with those farmers who have participated in the Farm Accountancy Data Network (FADN)[7], and then expand the list of potential collaborators from there, for example, with other farmers with whom there have already been relationships and collaborations in other projects, initiatives, or studies. Ideally, we would work with them for several years, not only establishing a punctual and specific collaboration, as the issue of losses is so complex that it should be addressed over several years, not just by measuring in a single agricultural campaign. Within this explanation, certain aspects should also be emphasised:
    - Conducting FL measurement processes on their farm does not imply culpability on the part of the farm's responsible parties. As mentioned earlier, the agri-food chain is a complex system with multiple interrelationships, and the activities at one point in the chain can have consequences elsewhere in the chain. Therefore, it is crucial not to view the issue of FL as a "taboo to be swept under the rug", but quite the opposite: it is a problem that adversely affects primary production. Its underlying drivers must be identified so that through joint efforts among various entities within the agri-food system, this FL can be reduced, benefiting the primary sector in particular.
    - It is essential to establish an environment of mutual trust between the public administration and the producers. Studies have found that the generation of FLW carries ethical and moral connotations that can lead to denial of this reality [20], carrying a risk that entities avoid quantifying the true magnitude of FL. To promote this relationship of mutual trust, direct contact with farmers is extremely beneficial, as well as the establishment of producer organisations as "bridge entities" that facilitate dialogue and understanding between the public administration and farmers. This dialogue should be a two-way flow, where producers feel heard and are not merely passive actors complying with the requirements of the public administration
    - Reducing FLW should be seen as an opportunity for improvement in the productive sector. In this regard, it may be necessary not only to highlight the negative consequences at the environmental and social levels but also at the economic level. This economic approach can be framed from the perspective of the farmer: the volume of food that is not only discarded from the supply chain but, in many cases, is perfectly edible for people, yet farmers are not

[7] Farm accountancy data network (FADN). Link to the website.

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compensated for it, resulting in lost income and putting pressure on the productive sector to intensify its cultivation. Displaying this circumstance is considered crucial for the farmer's engagement, so it should be addressed as one of the first aspects in these initial conversations.

  - The quantification process should be as straightforward as possible, minimising disruption to regular activities within primary production. Balance must be struck between accuracy and feasibility when selecting data collection methods. For example, digital tools for measuring and reporting FLW may bring more accuracy but pose challenges for actors without digital skills. Engaging in dialogue with the sector itself to reach a consensus on this balance will also be a critical factor.

- Another approach, already mentioned previously, is to select plots with which there have been previous collaborative ties, ensuring cooperation with the processes of measuring FL.

- A final option that allows for the broadest data collection is through the approval of legal regulations (national, regional, or local) that compel actors in the chain to measure FLW. An example of this is the law against FLW in Catalonia[21]. This law places one of its primary obligations on food chain companies, social entities, and other non-profit organisations involved in food distribution. These entities are required to reduce, measure, and annually report the amount of FLW, following the terms and conditions specified in subsequent regulations. This obligation applies to enterprises with more than ten employees and an annual business turnover or annual balance sheet exceeding two million euros. Micro-enterprises are exempt from this obligation. Alongside regulation engagement processes should be carried out to avoid being perceived as a government imposition on a territory that exacerbates issues in the primary sector, but rather as the opposite: a way to aid improvement.

In any of these approaches, willingness from the producers to participate in the quantification process is essential. Only once this agreement and willingness to carry out the quantifications or allow them to be conducted on their plots (as determined by the relevant public administrations) is obtained, it will be possible to establish the steps to carry out the quantification processes for FL in a given territory.

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3 HOW & WHEN? Measuring food loss at farm level

The objective of this chapter is for the reader to understand how to plan the quantification of food loss on a farm through the following steps (Figure 13):

1. Gathering basic plot-farm data through perceptual approach, and food loss drivers
2. Designing the sampling in the plot
3. Measuring food loss in the samples on the field
4. Analysing and extrapolating data to estimate total food loss in the plot

Additionally, at the beginning of the chapter, an analysis of the literature for quantification methodologies is presented (Ch. 3.1.).

Target audience: public administration, researchers, agrifood companies, farmers, livestock breeders, and companies involved in fishing/aquaculture.

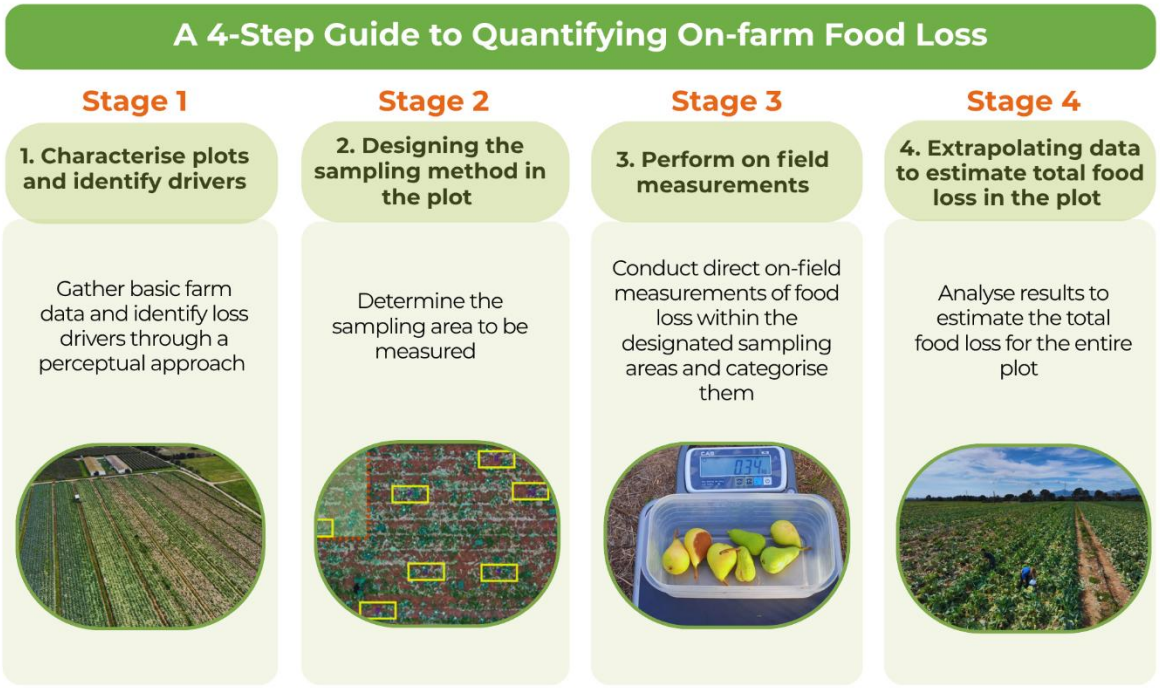

Figure 13. Visual description of the steps to take for measuring FL at farm level. Source: authors' own elaboration.

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3.1 State of the art of food loss and waste measurement processes

In the previous chapter, a methodology was proposed for how to approach a diagnosis of FL within a territory. Among the points addressed, the level of data disaggregation required for extrapolating FL data at a territorial level was discussed. This process can be summarised by the traditional phrase "*we cannot compare apples and pears*". Two methodological improvements have been proposed to avoid conducting extrapolation processes uniformly across economic activities and non-food products, and minimising error in the obtained figures.

The aim has been to establish more complex but specific extrapolation processes applied to different economic activities and food commodities, which can lead to more accurate figures. As described in the previous chapter, it involves determining which economic activities and food commodities should be grouped or not for these extrapolation processes and then calculating indices that can be applied to each of these groups.

This chapter focuses on the second part: calculating FL indices that can subsequently be applied to each group of economic activities/food commodities. To achieve this FL index, it is necessary to build upon the various quantification methods for FW and FL, as identified in the most relevant literature to date[22].

There are no standardised and specific quantification methodologies for primary production except for the standardised guidelines used for the entire agri-food chain[2,23].

However, in recent years, various attempts have emerged to seek standardisation of processes for quantifying losses[24–29], at least for certain types of food. It can collectively help establish common patterns in quantification processes and specific criteria for diagnosing FL based on product typology or economic activity within the primary sector.

Thus, this quantification manual aims to bring together previous knowledge, alongside the field experience of Espigoladors and the other partners, to achieve the dual purpose of identifying common patterns and establishing specific requirements based on product typologies and/or economic activities. However, as mentioned, this manual has been a living document, enriched by all initiatives, both within and outside the FOLOU project. Within FOLOU, a series of innovative technologies are being developed in WP3 such the case of tractor embedded video cameras, the use of Unmanned Aerial Vehicles (UAVs), Satellite technologies, multi-spectral cameras (VIS+NIR), blockchain tools and a Market Demand tool based on data from Social Networks for FL estimations (for more information, please refer to “Chapter 5”).

Table 11 presents the main methods for measuring FW throughout the food supply chain, as identified by the Delegated Decision 2019/1597. These methods are divided into two main groups. The first group consists of direct measurements, which the Delegated Decision 2019/1597 states should be used by entities with direct (physical) access to food waste to measure or approximate food waste. The second group includes the methods referred to as "other methods," which are used when direct (physical) access to FW is not available or when direct measurement is not feasible. This second group of methods has also been categorised as indirect methods.

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Table 11. Some definitions of quantification methods recommended by the Delegated Decision 2019/1597

Methods based on direct access to food waste/direct measurement	
Direct measurement (weighing or volumetric assessment)	Use of a measuring device to determine the mass of samples of FW or fractions of total waste, directly or determined on the basis of volume. It includes measurement of separately collected FW.
Scanning/Counting	Assessment of the number of items that make up FW, and use of the result to determine the mass
Waste composition analysis	Physical separation of FW from other fractions in order to determine the mass of the fractions sorted out
Diaries	An individual or group of individuals keeps a record or log of FW information on a regular basis.
Other methods	
Mass balance	Calculation of the amount of FW on the basis of the mass of inputs and outputs of food into and out of the measured system, and processing and consumption of food within the system.
Coefficients	Use of previously established FW coefficients or percentages representative for a food industry sub-sector or for an individual business operator. Such coefficients or percentages shall be established through sampling, data provided by food business operators or by other methods.

Within these different quantification methods, the Delegated Decision 2019/1597 recommends the use of some of them depending on the stage of the food chain to be monitored.

Table 12 presents the different methodologies for quantifying FW recommended by the Delegated Decision 2019/1597 based on the main stages of the agri-food chain, which can be used either exclusively or in combination. In the case of primary production, the following methods would be identified:

- Direct measurements
- Mass balance
- Questionnaires and interviews
- Coefficients and production statistics
- Waste composition analysis

Therefore, when measuring FL, it is advisable to follow the recommendations of the Delegated Decision 2019/1597.

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Table 12. Methodology for the in-depth measurement of FW recommended by the Delegated Decision 2019/1597

<table>
<tr><th>Stage of the food supply chain</th><th colspan="4">Methods of measurement</th></tr>
<tr><td>Primary production</td><td rowspan="5">Direct measurement</td><td rowspan="2">Mass balance</td><td></td><td colspan="2" rowspan="2">• Questionnaires and interviews
• Coefficients and production statistics
• Waste composition analysis</td></tr>
<tr><td>Processing and manufacturing</td><td></td></tr>
<tr><td>Retail and other distribution of food</td><td rowspan="3">Waste composition analysis</td><td rowspan="2">Counting/scanning</td><td></td></tr>
<tr><td>Restaurants and food services</td><td></td><td rowspan="2">Diaries</td></tr>
<tr><td>Households</td><td></td><td></td></tr>
</table>

According to the framework proposed by the Delegated Decision 2019/1597, it may seem that all methods are equally valid for measuring FW in terms of data reliability and the associated costs. However, a literature review assessing the accuracy, reliability, as well as budgetary and time costs of these methods found that the most reliable methods are also the most expensive, with direct measurements and waste composition analysis being particularly noteworthy in this regard. Therefore, in the measurement processes, a balance must always be sought between data reliability and the necessary costs to carry them out[30].

Measuring both FL and FW should not be exclusively focused on a quantitative perspective, i.e., solely pursuing a final number. It is equally important to identify the underlying reasons behind the generation of that number. Therefore, it is necessary to pursue the comprehensive analysis of various economic, environmental, technical, and socio-cultural factors that are closely intertwined and contribute to the final measurement result. This approach enables us to establish more robust problem diagnoses and, consequently, be better positioned to develop improvement and reduction proposals for food loss[30,31].

Taking all of this into account, this chapter will be broken down into the distinct phases that need to be considered to carry out a study on FL in a given territory.

The basic unit of measurement used is a plot, understood as "the entire area where a crop is predominantly cultivated and delimited by roads, canals, etc." It is important to note that a single agricultural farm can have one or several plots.

To estimate the total FL of the farm, a form should be completed for each quantified plot, and the results should be to reach the total predetermined sample. This way, information about the FL generated and its main drivers per crop in the territory will be obtained.

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In this stage, the goal is to establish the characterisation of the entire farm and collect information from the measured plots. It is possible for a single farm to have multiple plots to analyse, which is a simpler and less costly approach than measuring each plot randomly, among randomly selected farms.

3.1.1 Clarification of production methods definitions (conventional, organic, and agroecological)

First, it is important to establish definitions of what is considered conventional, organic, and agroecological production. This distinction is deemed relevant within the FOLOU project, as the various case studies aim to analyse, as far as possible, the differences in terms of FL that may arise between these three production systems. To facilitate understanding, FOLOU proposes, particularly for organic and agroecological production cases, to use both official definitions aligned with the European Commission and more concise, user-friendly definitions for the general public:

Proposed formal definitions, aligned with the European Commission:

- **Conventional**: Business as usual.
- **Organic**: According to the European Commission, organic farming is a production method aimed at obtaining food using natural substances and processes. Therefore, organic farming tends to have a limited environmental impact, as it promotes:
    - responsible use of energy and natural resources.
    - maintenance of biodiversity.
    - conservation of regional ecological balances.
    - improvement of soil fertility.
    - maintenance of water quality.

    In addition, organic farming standards pursue a high level of animal welfare and require farmers to respect the specific behavioural habits of animals.

    By its design, EU regulations on organic farming provide a well-defined framework for obtaining organic products throughout the EU. The goal is to meet the demand for reliable organic products emanating from consumers and simultaneously ensure a fair market for producers, distributors, and marketers.

    For farmers to benefit from these methods, consumers must be able to trust that organic production standards are being respected. To achieve this, the EU maintains a strict system of control and compliance assurance that validates the correct application of organic farming standards and regulations. Organic farming is part of a broad supply chain that includes other links (processing, distribution, and retail), also subject to control:

    - Each EU country designates its "control bodies or authorities" responsible for inspecting agents in the organic food chain. Before being able to market their products as organic, producers, distributors, and marketers must register with their local control body.
    - After the corresponding inspection and control, they are granted a certificate guaranteeing that their products comply with organic standards.

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- All operators must undergo at least one annual check to demonstrate continued compliance with the standards.
- Imported organic foods are also subject to control procedures to confirm that they have been produced and transported in accordance with the principles of organic farming.

- **Agroecological**: According to the European Commission's Joint Research Centre, agroecological approaches are, by definition, linked to the territory and its characteristics, including traditional knowledge and local genetic resources. For these reasons, there is no definitive set of practices that can be labelled as agroecological, but rather general principles that must be followed:
  - Dependence on ecological processes rather than purchased inputs;
  - Fair, environmentally friendly, locally adapted, and controlled practices.
  - Systemic approach that encompasses the management of interactions between components, rather than focusing solely on specific technologies.

  Furthermore, there is a consolidated set of 13 agroecological principles that must be followed to be considered agroecological production:
  - Recycling. Preferentially use local renewable resources and close nutrient and biomass cycles from resources as much as possible.
  - Input reduction. Reduce or eliminate reliance on purchased inputs and increase self-sufficiency.
  - Soil health. Ensure and improve soil health and functioning to enhance plant growth, especially through organic matter management and encouraging soil biological activity.
  - Animal health. Ensure animal health and welfare.
  - Biodiversity. Maintain and enhance species diversity, functional diversity, and genetic resources, thereby maintaining overall agroecosystem biodiversity over time and space at field, farm, and landscape scales.
  - Synergy. Enhance positive ecological interaction, synergy, integration, and complementarity among agroecosystem elements (animals, crops, trees, soil, and water).
  - Economic diversification. Diversify incomes on farms by ensuring greater financial independence for small-scale farmers and value-added opportunities, while enabling them to respond to consumer demand.
  - Knowledge co-creation. Encourage co-creation and horizontal knowledge exchange, including local and scientific innovation, especially through exchange between farmers.
  - Social values and diets. Build food systems based on the culture, identity, tradition, social equity, and gender equity of local communities, providing healthy, diverse, culturally and seasonally appropriate diets.
  - Equity. Support dignified and secure livelihoods for all actors involved in food systems, especially small food producers, based on fair trade, fair employment, and fair treatment of intellectual property rights.

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- Connectivity. Ensure proximity and trust between producers and consumers by promoting fair and short distribution networks and reintegrating food systems into local economies.
- Land and natural resource governance. Strengthen institutional links to improve governance, including the recognition and support of family farmers, smallholders, and peasant food producers as sustainable managers of natural and genetic resources.
- Participation. Encourage social organisation and increased participation in decision-making by food producers and consumers to support decentralised governance and local adaptive management of agricultural and food systems.

Proposed user-friendly/operative definitions for the general public:

- **Conventional**: Business as usual, using chemical inputs.
  - Integrated production: intermediate production systems between conventional and organic production.
- **Organic production**: Refers to any production that is officially certified with specific seals for this type of production.
  - Uncertified organic production: It is basically organic production without being certified with special seals (many farmers use this option to avoid the expensive costs of certifications).
  - For animal farming, organic production typically involves feeding animals organic products and ensuring specific welfare conditions that exceed those required for conventional production.
- **Agroecological production**: Agroecology is like cultivating an intricate ecosystem on the farm: it's about nurturing soil health, fostering diverse habitats for plants and animals, and promoting natural cycles without heavy reliance on external inputs. Unlike organic farming, which follows specific certified practices, agroecology is adaptable and embraces local wisdom, integrating ecological processes to create resilient farms that thrive sustainably within their unique environments. It's about cultivating not just crops, but whole ecosystems that support biodiversity, community well-being, and sustainable food production. Usually, they also sell their products at local scale using short-supply chains.
  - **Regenerative**[8] and **biodynamic**[9] agriculture, for instance, would also fall into this category.
  - For animal farming, there is also agroecological production. However, for aquaculture it might be difficult to adapt… but it would be a traditional fish or mussel production at small scale, maybe more as it was typically done during the old times, or very closely linked to animal welfare and the environment. Also, as mentioned before, it has to do with commercialising their production at a local scale.

[8] https://regenerationinternational.org/why-regenerative-agriculture/
[9] https://demeter.net/

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3.1.2 On-fields measurements' literature and recommended weighing area

Literature on FL measurements has also discussed the optimal area or portion of the plot to study to quantify FL, when it is not possible to weigh the entire plot area. Such studies do not seem to reach a general conclusion, depending on the type of crops or the institution/author conducting the quantification work. The most demanding percentages appear in the Danish initiative called "Danmark mod madspild"[32], which recommends weighing at least 10% of the total plot area where FL measurements are to be carried out.

These percentages on the plot area are highly variable and sometimes poorly defined, depending on the crop types. For instance, the FAO provides recommendations for calculating FL in cereals and pulses[33], where at least two samples per plot are recommended. However, a single sample with a sufficient size to ensure data reliability could also be used. As a general rule, a frame of around 10m x 5m or 5m x 5m is suggested, though smaller frames may be used for crops with high densities, such as rice.

In certain cases, measurements of FL in crops have been carried out using smaller sampling frames, as seen in the studies of peas and wheat in Finland[34], where four random samples, each covering a 1 m^2 area, were taken per plot. However, the percentage of the sampled area relative to the total plot area is not clear in this case.

Vegetables are another major category for FL measurements, with a wide variety of sample area sizes, depending on the territory covered by these samples or the percentage of the total plot area.

For example, a study on carrot losses in Sweden, which is also mentioned in the same report as the peas and wheat study in Finland, used samples of approximately 10m x 1.20m (12 m^2) for each plot, regardless of the plot size. In other loss studies in Norway, also mentioned in the same reference, three random areas, each measuring 6m x 1.5m (9 m^2) and a depth of 30-40 cm, were measured. In Sweden, loss measurements were also conducted for red and yellow onions, and the plots were divided into two parts. Each part was investigated with three frames measuring 1.80m (the width of the row) x 10m, resulting in a total of six frames investigated for each plot. Thus, it can be observed that the sampling frames varied from 9 to 18m^2 for each sample, with no calculations regarding the percentage of the sampled area relative to the total plot area. In a lettuce loss study in Sweden, larger sampling frames were used[35], where sample areas of 24 to 30 m^2 were marked and harvested and the losses per square meter were calculated.

Within the vegetable crops, covering a wide variety of different foods, there have been some proposals for standardised quantification methodologies for certain relatively similar crops, combining some vegetables with tubers and roots, based on the analysis of potato losses in Germany and Austria[24]. This approach could be applied to crops such as sweet potatoes, sunchokes (Jerusalem artichokes), onions, carrots, beets, etc. In this case, the primary unit of sample delineation is proposed to be the measurement by rows. The studies conducted have covered a total length ranging from 40 to 150 meters. This total length has been divided into different samples. For example, with a total length of 80 meters, 8 random samples of 10 meters in length were taken. In the case of roots such as potatoes, it is important to consider that the quantification will be more resource intensive as part of the produce will be buried and will have to be collected from inside the field, as indicated in previous studies.

The number of sampling areas, relative to the total plot, is not completely defined by these studies. However, in the case of a total length of 150 meters, the sample size ranged from 90 to 112.5 m^2, larger than the measurements mentioned in the Nordic country studies.

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Nevertheless, this area corresponds to a sample of about 0.60% to 0.25% based on the total area of the two plots analysed.

A rather particular case is found in quantifying losses in greenhouses. There are studies quantifying losses, especially in tomato cultivation, where the sampling areas are typically larger than those in outdoor crops. For instance, in New Zealand FL was quantified using two different methods: a counting system for unharvested tomatoes in the greenhouse runs (4% of the total number of rows were selected), and the total weight of rejected tomatoes from the harvested tomatoes at the greenhouse, packhouse, and sales warehouse[36]. In the UK (United Kingdom), studies covered samples of 7% to 50% of the total production[37].

In North Carolina (United States) studies on vegetable losses also aim to establish standardised quantification processes for this type of crop in a generalised manner[26]. The minimum sample size has been defined as three random rows of 15.24 meters in length. These rows were marked, harvested, and evaluated. The mean field size for each crop ranged from 1.07 ha to 11.13 ha, averaging 4.70 ha. This average has been used as a reference for the loss quantification methodology in vegetable crops.

This recommendation of three adjacent rows of 15.24 meters in length could be expanded in order to sample at least 0.1% of the field area, a much lower percentage compared to the Danish recommendation of 10% of the entire plot. This 0.1% sample size has also been applied in loss measurement studies for cauliflower[38]. In this case, 20-meter areas were randomly sampled, two rows wide including furrows, with an average of 10 sample areas per plot.

Following a similar methodological approach, studies were conducted to calculate losses in northern and central California (United States)[28]. In this case, the number of rows was increased within a range of 4 to 12, each with a length of 7.6 to 30.5 meters. The choice of margins depends on the type of crop to be quantified. For crops with a large amount of unharvested, edible product remaining, such as Romaine hearts, standard plot sizes were 4 rows by 7.6 meters. For crops with relatively little remaining edible product, such as sweet corn, typical plot sizes were 10 to 12 rows by 30.5 meters. In any case, the sample sizes used for each type of crop varied widely, ranging from 34.4 to 407.5 square meters. This study recommends quantifying losses in at least 4 different plots per crop.

The recommendation of using rows of 15 meters as a sample reference is also considered applicable for fruit crop measurement. In this case, a minimum reference is also recommended, although it is noted that it could be reduced by half if speed in sample collection is preferred over data reliability.

In studies analysing fruit crop losses through weighing, the focus is not only on the delimitation of sample sizes in terms of land area by rows but also on tree counting within the plot. This is the case in studies in the United Kingdom[37], where for quantifying losses in apple crops, a framework of 10 by 10 trees was established for 3 different plots. These sample frameworks represented between 0.1% and 1.5% of the total number of trees per plot. These percentages of sampled trees in relation to the total plot were higher in the study of losses in Valencian persimmon[29], ranging from 3% to 16.7%. For this, 10 trees were measured in each plot, covering a total of 12 plots.

In the case of berries, due to the size of their plantations and the reduced distance between them, it would be more advisable to delimit the sampling areas based on distance rather than tree/shrub counting. An example of this approach is seen in studies conducted in the United Kingdom with blackcurrants[38], where sampling areas of 1.5 x 3 meters were delimited for each plot, and measurements were taken from 5 plots. This represented a percentage of the total land area ranging from 0.06% to 0.17%. Table 13 and Table 14

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summarises all the preceding information, presenting the key data regarding field sampling for the measurement of FL.

Table 13. Summary table with key data on FL sampling in the fields of the analysed studies (Part A).

Country/Entity	Food commodity	Sample size	Type of frames
Denmark[32]	All	≥10%	
FAO[33]	Cereals and pulses	(-)	10m x 5m or 5m x 5m (smaller if high densities)
Finland[34]	Peas and wheat	(-)	1 m^2 area per plot
Sweeden[34]	Carrots	(-)	10m x 1.20m (12 m^2) for each plot
Norway[34]	Carrots	(-)	three random areas, each measuring 6m x 1.5m (9 m^2) and a depth of 30-40 cm
Sweden[34]	Red and yellow onions	(-)	Six frames of 1.80m (the width of the row) x 10m
Sweden[35]	Lettuce	(-)	Sample areas of 24 to 30 m^2 per plot
Germany and Austria[24]	Potatoes	0.60% to 0.25%	a total length ranging from 40 to 150 meters (e.g. a total length of 80 meters, 8 random samples of 10 meters in length)
New Zealand[36]	Tomatoes (in greenhouses)	4%	4% of the total number of rows
United Kingdom[37]	Tomatoes (in greenhouses)	7-50% (total production)	(-)
North Carolina (USA)[26]	Vegetables	≥0.1%	3 random rows of 15.24 meters in length
United Kingdom[38]	Cauliflower	0.1%	20-meter areas were randomly sampled, two rows wide including furrows, with an average of 10 sample areas per plot
Northern and central California (USA)[28]	Crops (in general)	(-)	4 to 12 rows, each with a length of 7.6 to 30.5 meters

Table 14. Summary table with key data on FL sampling in the fields of the analysed studies (Part B).

Country/Entity	Food commodity	Sample size	Type of frames
Northern and central California (United States)[28]	For crops with a large amount of unharvested, edible product remaining, (e.g. Romaine hearts)	(-)	4 rows by 7.6 meters
Northern and central California (United States)[28]	Vegetables. For crops with relatively little remaining edible product, such as sweet corn.	(-)	10 to 12 rows by 30.5 meters
United Kingdom[37]	Apples	0.1% and 1.5%	Framework of 10 by 10 trees per plot
Spain[29]	Persimmon	3% to 16.7%	10 trees per plot
United Kingdom[38]	Blackcurrants	0.06% to 0.17%	1.5 x 3 meters per plot

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For what concerns the timing of conducting the measurements, studies conducted in northern and central California[28] emphasise the importance of quantifying FL even on the same day as harvesting, especially for some crops that deteriorate rapidly in the field, such as leafy greens. The same study highlights that for field-stable crops that do not deteriorate rapidly in the field, such as melons, the survey could be conducted several hours after harvest without impacting the results.

Measurement studies of carrot losses in Finland[34] also opted to measure on the same day as harvest, except for one plot that was measured two days later due to an early harvest. The same strategy was used for measuring carrots in Norway, and onions in Sweden and the United Kingdom: measurements were taken on the same day or the day following harvest.

There is also a formula to carry out pre-harvest and harvest FL measurements: conduct measurements on losses before farmers or harvesting machinery arrive at the site, and then measure harvest losses just after the pass of the farmers/machinery. This strategy was used for calculating FL in pea and wheat crops in Finland and for blackcurrants in the United Kingdom[38].

The studies on FL in the United Kingdom also agree on this narrow margin for calculations of pre-harvest and harvest losses. For measuring apple losses[37], it was done over a two-day period, just before and after harvest. Other types of crops, such as cereals, also followed this strategy, measuring on the same day or a day after harvest.

The mentioned study on potato FL in Austria and Germany[24], besides measuring losses on the same day as harvest, also suggests the possibility of working with farmers to agree on a harvesting method that allows for measurement without destroying the sample. An example is related to the oversized or damaged potatoes, which are automatically or manually rejected and thrown on the field by passing funnels. Subsequently, this FL falls beside the harvester and is at risk of being damaged when the harvester returns for the next row. For this reason, sampling areas and data collection times were identified based on the movements of the harvesting machinery.

3.1.3 Literature on interviews as measurements' methodology

As introduced earlier, an alternative or in parallel to on field measurements, interviews with relevant stakeholders can be conducted to obtain an estimate of food loss based on farmers' perspectives. Literature on the topic [39] recommend conducting semi-structured interviews, which allows for both following standardised questions/aspects (Table 26-PartA, Table 27-PartB, and Table 28-PartC), and the flexibility to deviate from predefined questions and issues, thus allowing for emerging and raising unforeseen questions.

As this study indicates, given the sensitive and complex nature of on-farm FL, semi-structured questions may support a more effective exploration of the topic, enabling farmers to share their perceptions, expand on their responses, and highlight unforeseen issues, while shedding light on how the analysed factors interact.

This type of semi-structured interviews may be better suited to complex issues that significantly affect the amount of FL. A clear example is identifying how farmers determine when it is time to stop harvesting a given crop.

In this regard, the aforementioned study, led by Lisa Johnson, developed a decision tree (Figure 14). It shows a practical method by which growers determine whether or not to

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continue the harvest. This decision tree could also help identify key areas for intervention to reduce on-farm losses.

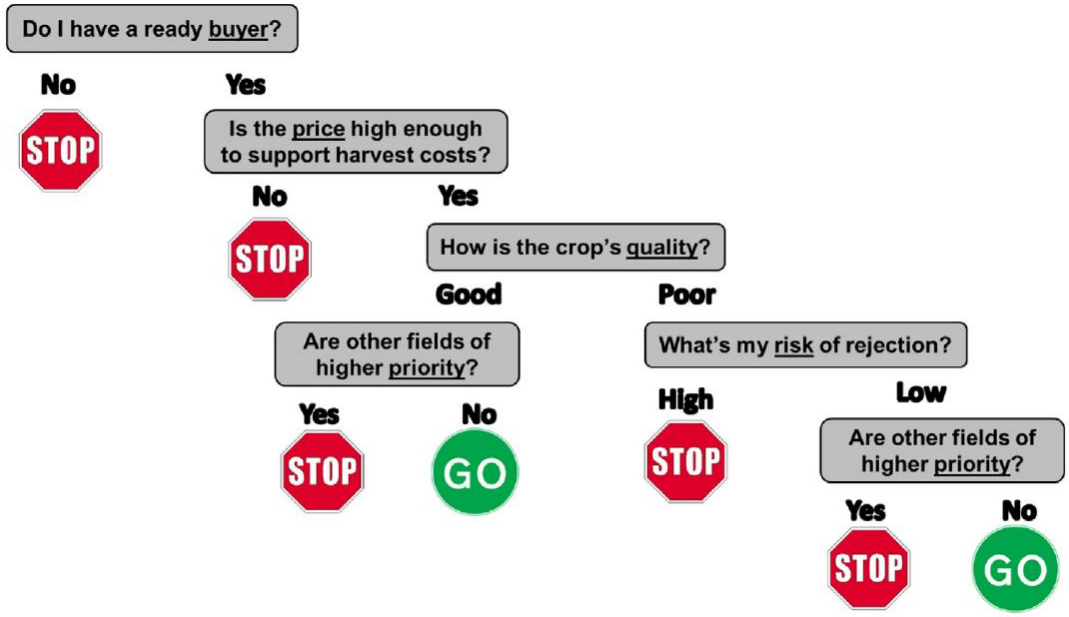

Figure 14. Decision tree illustrating the questions growers use to determine whether to continue the harvest in vegetable crop production. Source: Johnson L. et al (2019) [39].

Thus, interviews allow this information to be obtained in a more personal and robust manner, as the meaning of each question can be explained. Therefore, if questionnaires are used, it is crucial to have a well-developed and validated questionnaire to avoid confusion and potential reluctance to participate, as highlighted in the study on FL in Finland through questionnaires [40].

3.2 Food loss direct measurement protocol

The main objective of this chapter is to provide a protocol on how to directly measure FL. While the scope of this Manual is to provide a general guide on how to measure FL for different commodity types, the methodologies described here are primarily those most suitable for crops (e.g. fruits, vegetables, potatoes and cereals). This is mainly due to the fact that, according to the experience from the case studies in task 4.2 (WP4), direct measurement has proved to be primarily feasible for crop production, whereas in the aquaculture and livestock sectors it is more challenging and the analysis needs to rely more heavily on existing records.

The methodological considerations for each case study tested (vegetables, fruit, cereals, potatoes, mussels, salmon, meat and milk) are set out in Annex 8.3.

To facilitate understanding the manual, the FL quantification process has been divided into different steps:

1) Gathering basic plot-farm data through perceptual approach, and FL drivers (3.2.1)
2) Designing the sampling in the plot (3.2.2)
3) Measuring FL in the samples on the field (3.2.3)
4) Analysing and extrapolating data to estimate total FL in the plot (3.2.4)

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3.2.1 STEP 1. Gathering basic plot-farm data and food loss drivers through perceptual approach

3.2.1.1 Importance of collecting information through a perceptual approach and key aspects to address

It is important to highlight the significance of collecting perceptual information as a preliminary step to direct measurements. This process of gathering preliminary data can provide a wealth of information about the context of both the plot and the crop itself, as well as the market for this product, which is recommended to be collected to obtain a broader understanding beyond the specific measurements taken.

This is important because, as mentioned in the EIP AGRI Focus Group (FG)[41] "*there is no 'typical season'*" and therefore, although the ideal measurement would span more than one growing season, as mentioned, quantifying FL in the same plot would benefit from monitoring over multiple growing seasons.

However, in the face of possible resource limitations, one solution is to rely on explanations provided by farmers themselves regarding the upcoming growing season to be quantified, including estimates of total production and the percentage that will be marketable. They can also provide context on the productivity of that specific plot compared to similar plots in the area, as well as technical characteristics of the crop type (seed variety, plant spacing, soil type, etc.).

Another aspect to gather is the market behaviour in relation to the crop being quantified, as well as the producer's forecasts. Market dynamics is a very broad concept that encompasses the interaction of supply, demand and price. Within this framework, recent studies have highlighted how the concentration of power influences particularly the agri-food system [42,43] and contributes to FL food loss creation [44–46]. For the purpose of this manual, this includes understanding the characteristics required for a crop to be considered "marketable," such as size, shape, appearance quality, etc. Thus, it is very relevant because cosmetic specifications and marketing standards for food products, particularly those set by private retailers rather than public regulators, are a major driver of food loss and waste across the supply chain [46–54]. Here, two food material flows are worth examining:

- The estimated quantity of the total production that the producer expects to discard and will not be marketable, as well as its final destination;
- The marketable volume of the product and its possible destinations (e.g. supermarkets, wholesale markets, school canteens, industry), since each market destination offers a different price and may determine whether collecting the product is economically worthwhile for the farmer.

For the design of the loss measurement schedule, it will be necessary to gather information about the harvesting process, the estimated dates for harvesting, and whether one or multiple cuts (harvest) will be made during this process. This last piece of information is crucial for making estimations if it is not possible to measure after each cut, and measurements will be taken fewer times than the number of cuts made throughout the entire agricultural campaign. A preliminary approach to this calculation would be to multiply the collected FL data from one cut, for example, by the number of cuts per year. However, there are crops where the harvested volume differs between cuts, and therefore, it would be helpful for farmers to provide estimates on the representativeness of the FL measured after the sampled cut.

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As an example, in a watermelon crop, there may be 4 cuts per year, and losses from the first cut will be measured. If the loss data is simply multiplied by four, it may differ significantly from reality because, for instance, the first cut may have a larger harvest volume, resulting in overestimated numbers. Of course, a larger harvest volume does not necessarily imply a higher volume of FL. For instance, in some cuts, the market may accept the product better, leading to a lower loss ratio.

These interviews will also help us determine how to conduct the measurement processes to minimise inconvenience for farmers. They will also assist in identifying the sampling areas within each plot if, due to resource limitations, it is not feasible to measure the entire plot or if complete measurement is highly complex and costly due to the crop type.

When determining the representative area of the field, it is important to exclude the plot border to avoid edge effects. Some studies[28] have used a reference point of measuring losses at least 30 feet (9.1 meters) from the field's border. However, this recommendation should not completely exclude the study of plot borders, as there are measurement studies [38] where these areas were precisely identified as hotspots of FL, because growers identified row ends as potentially higher areas of FL, due to the mechanics of the harvest machines. Considering all of the above, it is important to consider that plot borders may not be representative of the total production and potential generation of losses in the plot. However, they should not be completely disregarded when locating different sample areas, which would mainly focus on the most representative zones of the crop but including plot borders to a lesser extent.

Additionally, the level of homogeneity of the crop within the entire plot being quantified should be considered. If the crop is highly heterogeneous, random sampling for the entire area, excluding the plot border, is recommended. Sometimes there may be a relatively homogeneous zone in terms of productivity and specific relatively small areas within the entire plot that have production differences, in which case measurements should prioritise the larger homogeneous zones.

This collection of perceptual information will also provide valuable data to identify the reasons why the farmer considers food products to be discarded in primary production, either during the pre-harvest process or during harvesting. This identification of reasons gathered through interviews/questionnaires aims not only to provide a more comprehensive temporal framework about the evolution of the factors that may have led to potential discards in primary production, but also complements the more precise "snapshot" obtained through direct quantitative methods (weighing).

Within these reasons, it will be necessary to understand, for example, what type of diseases and maladies affect the crops and whether this damage is purely aesthetic, making the products edible but non-marketable, or if it even renders them inedible. The reasons will also include the farmers' own knowledge and awareness of this issue, making it advisable to understand the farmers' prior estimations of potential losses and compare them with the actual data calculated through direct measurement to identify any differences obtained. Sometimes, these differences are the result of misperceptions or misjudgements of the extent of the problem sometimes because the market has skewed their view of what product could be considered as FL.

Once this information has been collected through interviews or questionnaires directed at farmers or plot owners, it is important to highlight the differences between the data obtained from these methods and data gathered through in situ measurements (weighing of losses directly in the field).

In situ measurements, such as using scales in the field, as we will see in the next chapter provide precise, quantitative data. This gives us a clear, objective number that reflects "what

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is actually lost" in terms of FL. This is empirical, measurable data that is fundamental for understanding the scale and magnitude of the issue in a highly controlled, accurate way.

On the other hand, data gathered from interviews and questionnaires, although often presented in numerical form (e.g., kilos, tonnes, percentages, ranges), largely reflects what the farmer thinks is lost. This type of data, while it may yield numbers, is based on perceptions, estimations, and subjective experiences of the respondents. As such, it leans more toward being considered perceptual or subjective data rather than strictly quantitative.

While it's true that qualitative data often involves narrative or thematic responses, it's essential to recognise that the data derived from interviews and questionnaires in this context can occupy a space between qualitative and quantitative. We might term it perceptual quantitative data or self-reported data. This category acknowledges that, although presented numerically, it's based on human perception and judgment, lacking the objective precision of direct field measurements. In fact, evidence has shown substantial differences between FLW quantification through interviews and weighing methodology [28,55].

Thus, while in situ measurements provide **empirical quantitative data**, interviews and questionnaires yield **perceptual quantitative data**, which, although numerically expressed, should be viewed in terms of its subjective, experience-based nature. This distinction is crucial to ensure both types of data are interpreted within their respective limitations and strengths.

However, obtaining both parameters is deemed highly valuable to gain a more comprehensive perspective on the issue. For instance, it is possible that one may believe that very little quantity is being discarded, but on-site measurements reveal significantly higher amounts. Conversely, it could also be the case that the perceived and actual quantities lost are quite similar. Thus, these two parameters provide two distinct diagnostics for the problem. Using this framework can inform policies aimed at addressing the root causes of loss such as unfair trading practices, lack of market alternatives for products that do not meet market requirements, or inadequate infrastructure [46,56–58].

Finally, it is important to highlight the contribution of these interviews to a fundamental aspect: building alliances with the productive sector of a territory. The lack of collaboration from this sector has been highlighted in various studies[59], often due to a lack of interest, not finding direct benefits in participating in such studies, or even due to shame around providing FL data, thinking that recording FL in their crops implies blaming them for the losses.

Therefore, it will be necessary not only to define with them what is understood by FL, so they can assess and delimit the problem, but above all, to explain that recording FL at a specific point in the chain does not mean guilt, and solutions to the potential problem will only be feasible if there is collaboration among different actors.

Measuring the scale of FL is the first step towards finding solutions. It is a problem that we, from different sectors and actors, must engage with so that the existing issues in primary production can be recognised. In this sector of the chain, farmers are producing more food than what eventually gets collected and paid for, leading to not only environmental, social, and economic implications for the entire territory but also affecting the future of our farmers. Only with their collaboration will it be possible to make reliable diagnoses and shed light on a problem that, to date, remains unknown to wider society.

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3.2.1.2 *Recommended methods and proposed information to be collected through a perceptual approach*

This first stage should be carried out through interviews with farm owners and/or farmers working in the area. If the latter options are not possible, it is recommended to use paper or online questionnaires, depending on the availability of the stakeholders.

This initial stage is crucial, as although this method is not considered the most reliable for quantitative studies[22,28,59], to establish the in-situ measurement plan and gather information on FL in each plot. The best time to conduct these interviews or send questionnaires would be in the weeks leading up to the harvest of the crop to be analysed. This way, the farmer can already have a very approximate harvest calendar, which is a fundamental piece of information for establishing the in-situ loss measurement strategy. Data collection methods are listed here from most to least preferable:

- 1. In-person interviews.
- 2. Telephone interviews.
- 3. Online or paper questionnaires.

Interviews and in-person methods are preferable for two reasons:

- Interviews, particularly those conducted in-person, provide time and space to build trust and shared understanding. This is especially important as the generation of FL can bring connotations of blame so measurement data should be gathered in a way that avoids this. Non-verbal cues and signals during in-person interaction can help interviewers to recognise when it may be necessary to clarify the intent behind specific questions and take time to build trust. This may involve recognising the systemic causes of FL and emphasising that the goal of measurement is to benefit the sector, rather than to assign blame. This interactive approach stands in contrast to questionnaires, which are completed independently and do not provide the opportunity for real-time clarification.

- Interviews can also help ensure the data gathered is accurate. Additional explanations and clarifications may be needed to ensure both parties understand measurement procedures in the same way. For example, the concept of 'food loss' has many definitions and may need to be discussed during the interview. In-person interviews conducted in-situ are ideal as they enable real-time discussion of the plot being measured.

Table 26-PartA, Table 27-PartB, and Table 28-PartC gather all the information discussed in this section, and it is considered of great importance for diagnosing the issue of FL in a plot. As you can see, part of the information collected through this method will directly contribute to providing a broader context to the basic data intended to be obtained through empirical methods (Table 29-PartA, and Table 30-PartB), demonstrating the clear contribution of a perceptual approach to the measurement of losses. When measuring FL on a farm, the following situations may occur, depending on the outcomes of the process “Where to quantify” (Chap. 2):

- Only one plot of a specific crop is to be quantified.
- Multiple plots of the same crop are to be quantified.
- Multiple plots of different crops are to be quantified.

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To narrow down this variety of situations, it is necessary to collect basic information, in addition to the necessary data for correctly identifying each farm. This will allow for the description of the characteristics of each farm to be analysed and provide a clear understanding of when to establish the measurement processes for losses during the pre-harvest and harvesting stages. Table 15 is an example of the type of information that needs to be gathered for each measured farm.

Table 15. Example of a form for characterising each farm to be quantified. Text in blue denotes an example using fictitious data.

Farm ID	27_County_9			
Location	County 9. Region X			
Crop(s)	Tomatoes, garlic and lettuce			
Name of crop	**NACE Class**	**CPA Code**	**Number of parcels/plots**	**Period(s) of harvesting**
Tomatoes	01.13 Growing of vegetables and melons, roots and tubers	01.13.34 Tomatoes	3	Jun-Sept
Garlic	01.13 Growing of vegetables and melons, roots and tubers	01.13.42 Garlic	5	Mar-Ap / Jun
Lettuce	01.13 Growing of vegetables and melons, roots and tubers	01.13.14 Lettuce	2	Jan-Dec

To accurately measure FL for each analysed plot (or its synonym "parcel"), it is necessary to collect a set of elementary information based on empirical data, that is, through on-site measurement of FL, as well as through the interviews with farmers. Such information is gathered in Table 29-PartA, and Table 30-PartB (Annex _8.1) and can be used as guideline for collecting empirical data for each analysed plot.

One of the key aspects to highlight is the drivers that farmers consider most important in relation to FL on their plot, farm, or pond. This manual suggests a set of drivers divided into three main categories (behavioural, societal, and environmental), each containing specific reasons. These categories have been established thanks to the work carried out by the participating entities of Work Package 2 of the FOLOU project (D2.2) [60], led by the University of Bologna (Italy). The idea is that the person responsible for measuring the FL can select some of these, as shown in Table 27 by way of example. To facilitate the understanding of these drivers, Table 34 Table 35 and Table 36 describe each of them according to the three main established categories.

As can be seen, both in the farmer interview example (Table 28) and in the form to be completed by the quantification technician (Table 30), the main drivers of FL are identified. This makes it possible to compare the reasons perceived by the farmer with those identified by the technician in the field, enriching the analysis and diagnosis of FL.

In addition, in relation to the FL drivers, it is also worth noting that Table 26-PartA, Table 27-PartB, and Table 28-PartC contain the most relevant information for conducting a perceptual analysis of the issue on the plot. However, it does not mean that these interviews or questionnaires have to be conducted in a completely closed and directed manner solely to complete those sections.

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In fact, based on the abovementioned literature (Par. 3.1.2), a standardised template is provided to establish these questionnaires (see Table 31-PartA and Table 32-PartB, in Annex). It is obviously more advisable to expand this set of questions included in Table 26-PartA, Table 27-PartB, and Table 28-PartC, as it would offer a broader context and therefore allows for a more accurate diagnosis. However, these basic questions are provided, many of which have been tested in surveys conducted by other studies as well.

3.2.2 STEP 2. Designing of a sampling method for direct measurements in the plot

Once we have collected all the perceptual information that provides us with a general context about the data to be directly measured through weighing, it would be time to design the sampling framework within each plot.

In Chapter 2.4, we discuss how to calculate the sampling frame, firstly, under ideal conditions, in relation to the total cultivation area of the food commodity where we want to measure its FL. Secondly, as previously described in section 2.4.2, there would also be other possibilities to define the sampling area, depending on the availability of information, such as production volumes or the number of farms related to that type of crop.

In any case, from the total extent of the crops related to a specific food product in a territory, a representative sample to be measured would have already been calculated, based on parameters related to the acceptable margins of error. Therefore, the most reliable estimation of FL in a territory would be gained through weighing the entire area delimited as the sampling area.

However, there may be situations of limited resources that prevent the execution of a task that could be demanding both in terms of economic costs and time. In this case, the question to be answered would be "what portion of the plot should be weighed if weighing the entire extent is not possible, to obtain relatively reliable information?"

Taking into account many of the proposals and conclusions from the studies analysed in Chapter 3.1.2, guidelines are provided regarding the sample size to consider for the analysis of FL in a territory and a specific crop, using weighing as the method. It is important to remember that we are determining the "sample of the sample," as in earlier stages, the number of hectares to be quantified was calculated in order to diagnose the problem of losses in a territory and a specific crop. These hectares have been selected in the form of farms and plots throughout the territory, and the following recommendations will outline how a portion of these hectares can be measured through direct measurement (weighing).

- Calculations must be made regarding the portion of the land covered by the sample in relation to the total plot. These calculations should be based on percentages, and while there is currently no clear consensus on these percentages, this manual proposes a categorisation based on the percentages used:
    - Percentages below 0.1% of the total plot: insufficient measurements
    - Percentages between 0.1% and 1%: sufficient but limited measurements
    - Percentages between 1% and 10%: significant measurements
    - Percentages above 10%: desirable measurements
- The design of the sampling framework will naturally be influenced by crop types, terrain characteristics, etc. However, as general recommendations, considering the main crop types.

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Cereals and pulses. According to the literature[33], the recommended frames dimension for cereal quantification are approximately 10m x 5m or 5m x 5m. It should be noted that, based on experience from the case studies (see Annex 8.3.3), smaller frames of 1 m × 1 m can also be used due to the density of cereal crops. The number of these samples per plot will be determined based on the percentage of the sample with respect to the total plot area to be considered.

Vegetables, roots and tubers. As a general guideline, based on the literature described in Section 3.1.2, conduct sampling with three rows of 15m length randomly. The number of these frames will depend on the percentage of the plot to be covered. For crops such as potatoes, sweet potatoes, sunchokes, onions, carrots, beets, etc., these frames can be established randomly in 10m rows. Furthermore, for this type of crops, it is recommended that the sampling area can be excavated to a minimum depth of between 15-30 centimetres. It should be noted that, based on experience from the case studies (see Annex 8.3.1), instead of basing sampling on linear rows, square frames can also be used. In the case of vegetables, frames ranging from 2.5 m × 2.5 m up to 8 m × 8 m have been found to be feasible for sampling, whereas for tubers such as potatoes, quantification has been shown to be possible using 1 m × 1 m frames.

Fruits. Similarly, you can utilise the methodology mentioned above or approach it based on the number of trees, randomly selected. The number of trees to be measured will be calculated based on the percentage of the total trees in the plot that you wish to analyse (See Annex 0).

- While the location of the sampling frames will be done randomly, it is advisable for the farmers themselves to help identify the most representative areas of the plot so that the frames especially cover these zones. This should not exclude frames that cover other less significant areas, especially the plot borders, as they can sometimes be the areas with the highest generation of losses, and even though it may be infrequent, it would be recommended to capture these data as well.
- These loss measurement processes should be carried out in at least 4 plots per specific crop type.

These general recommendations have been refined to adapt to the specific circumstances of different types of crops, as outlined in Annex 8.3. They will continue to improve through new guidelines, projects, and studies that arise or are planned.

In the context of livestock farming and fishing/aquaculture, new knowledge and methodologies for on-site measurements, especially through weighing, will be particularly important. This is due to the lack of experiences quantifying losses using this methodology in these sectors, as noted in some of the main literature reviews on FLW to date[22]. This manual already presents some advancements regarding the measurement of FL for these products (see Annex 8.3.5 8.3.6; 8.3.7; 8.3.8)

Therefore, the main recommendation for determining the sample would focus on earlier stages, calculating the sample size based on the number of identified companies/farms in the territory, according to the NACE class or CPA code. For example, let's consider calculating FL in the activity "01.47 Raising of poultry" in Region X (see Figure 7). The number of identified farms is 52. Depending on the statistical error to be assumed, a percentage of these 52 farms will need to be measured.

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Each of these economic activities, according to the NACE classes, and even each farm, may present FL hotspots that are very different throughout the entire food production process, so it will be necessary to consider them within the interview/questionnaire processes, which will greatly assist us in taking the next steps towards directly measuring FL.

Moreover, sometimes these processes are highly technified, as shown in the case of eggs in the United Kingdom[37], where detailed data on food production is collected daily. Thus, they did not need to do anything differently to their existing production practices to collect the data, and it could cover the monitoring of total FL in each of the identified farms.

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3.2.3 STEP 3. On-field measurement of plot-specific food loss

Once a sample area has been chosen, measuring FL through direct methods will involve the following stages:

- Quantification of pre-harvest and harvest FL
- Categorising FL and their drivers
- Weighing the identified FL

3.2.3.1 Quantification of pre-harvest and harvest food loss

The direct measurement process will consist of several in-situ measurements, as it aims to analyse both pre-harvest losses and losses that occur during harvest. This approach will facilitate identification of the drivers of these FL and potential solutions.

For this reason, at least two in-situ measurements should be conducted: one prior to harvest to quantify pre-harvest FL and another after harvest to quantify losses during harvesting[10]. To increase accuracy, both pre-harvest and harvest measurements should be taken as close as possible to the actual day of harvest. We recommend that measurements are ideally taken on the same day as harvest, especially for perishable crops, and if not possible then maximum 1-3 days before and/or after the harvest day.

This naturally makes FL measurement processes more complex and challenging, requiring closer communication with growers. However, on the other hand, it prevents a significant volume of the food from being lost, both in quantity and quality due to the highly damaged sample resulting from measurements taken in time frames far removed from the harvest period.

Therefore, farmers' estimates of harvest dates will be crucial in determining the schedule for direct measurement.

Given the convergence of strategies for measuring FL by weighing (Par. 3.1.2), it is recommended to conduct measurements for pre-harvest and harvest FL on the same day as harvest, especially for the most perishable crops. If this is not feasible, there should be a maximum time gap of 1-2 days before and/or after the harvest day for the measurements.

An even greater challenge arises with multiple-crops cuts, where several harvests take place throughout the year. In these cases, ideally, the operation should be repeated for measuring harvest losses as many times as there are cuts to be made. However, in many instances, this can be very complex to carry out due to budgetary or time constraints, or the inconvenience it may cause to the farmers. Therefore, if the number of measurements is reduced, it will be vital to collect amount of food harvested and lost estimates for each cut provided by the farmers so that the data obtained through weighing can be appropriately extrapolated to the total number of cuts. Certainly, the measurement that should always prevail over the rest of the cuts is the last one, at the end of the harvest.

Regardless of the number of cuts in the crops, another essential recommendation is to establish direct, smooth, and agile communication with the farmers so that prompt contact

[10] Pre-harvest losses can be due to pest infestations, diseases, climatic events (e.g. inundation, droughts), market constraints (food left in the field e.g., due to changing demand for produce or overproduction, as a consequence of delayed harvesting driven by market conditions), or technical issues (animal transportation deaths…), among others. Harvest losses can happen due to due to various reasons such as mechanical handling, market constraints discards based on aesthetic criteria, or losses caused by pests, among others.

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can be made in case the harvest day is modified, enabling timely establishment of direct measurements in the plots.

For the livestock and fisheries sector, similar approaches can be applied to the pre-capture/slaughter phases and the actual capture process. However, when it comes to slaughter, as it falls within the concept of FW, it would be excluded from the processes of measuring FL.

3.2.3.2 Categorising losses and their drivers

When collecting data through direct measurement, it is important to understand FL drivers and measure the FL according to each type of driver. This is why, prior to measurement, it is essential to pre-identify the main categories under which quantified foods will be classified. In other words, to identify and even measure the importance of the drivers associated with the losses, it is essential to avoid classifying all losses (pre-harvest and harvest) under a single category. Instead, they should be classified in different categories, each associated with different drivers that led to the losses.

For this purpose, a first recommendation is to talk to the farmers themselves to identify the main reasons for the losses and how these reasons have specific characteristics that can be recognised through visual inspection during quantification. Within these reasons, it would also be valuable to identify the main diseases and ailments and whether they render the food inedible or merely unmarketable but edible.

Among these categories, a fundamental one would be the identification of immature foods that are therefore inedible. Creating this category is crucial to separate the immature foods from the mature ones during the analysis of losses, as immature foods fall outside the definition of FL. The relevant characteristics to consider a food item mature enough to be considered as such, or conversely, deemed immature, depend on each type of food. For example, in the case of oranges, it's usually the size and colour. Identifying these characteristics for each food item is relatively straightforward in some cases and in others, it would be advisable to ask the producers.

From there, the different categories for mature foods can be arranged based on the different typologies/causes that one wants or can analyse through visual inspection. A simple initial categorisation to highlight is that used for measuring apple losses in the UK, which divides them into just two categories: "good" (no or very minimal visible damage or rot/disease) and "bad" (visible damage or rot).

Similarly, an increase to three categories was observed in the studies conducted in North Carolina [26] which identified three different categories: marketable, edible but not marketable, and unfit for human consumption.

These categories can be significantly expanded depending on the possibilities and/or objectives of the measurement processes. An example of this is the case of Valencian persimmons [29], where six different categories were created:

- Fruits potentially suitable for the human consumption but left in the treetops
- Deformed fruits
- Damaged by severe weather. Different types of superficial scars on the skin
- Damaged by the presence of pests
- Fruits that fell down due to breaking branches
- Fruits that fell down due to undefined causes

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- Damaged caused by manipulation during the harvesting process or fruits that were directly discarded

These categories can each be associated with different drivers, allowing for the generation of subtypes within the main categories. The measurement of the main categories, along with the perceptual approaches conducted in earlier stages and a literature review, will provide us with the primary drivers associated with the FL.

In fact, it is advisable that the design of this categorisation be developed in collaboration with the producers themselves to analyse aspects of FL that they also consider relevant and to provide useful data for their operations. This approach also fosters engagement with the sector. An example of this could be the creation of four main categories for the analysis of losses in oranges:

- Edible and Marketable (Fresh): Oranges that are perfectly edible for consumers and meet all aesthetic requirements for sale as fresh produce, particularly the calibre of the orange, which the market currently defines as requiring sizes between 67 and 103 millimetres.

- Edible but not marketable (by the market): In this case, these are oranges that are edible and meet the aesthetic criteria, particularly the calibre, established by European regulations for sale as fresh produce. However, despite this compliance, the markets reject them and do not consider them suitable for fresh sale. These oranges fall within a calibre range of 53 to 67 millimetres.

- Edible but non-marketable (neither by the market nor by European regulations): these are edible oranges that do not meet the aesthetic criteria, particularly regarding calibre, set forth by European regulations and the market. They include oranges that exceed 103 millimetres or do not reach a calibre of 53 millimetres.

- Unfit for human consumption: Those oranges that, for various reasons (severe mechanical damage, pests, diseases, etc.), are not edible, regardless of their calibre and other aesthetic parameters.

These categories can be visualised in Figure 15, where, from left to right, the oranges are identified as: Edible and marketable (fresh), Edible but not marketable by law (not by the market), Edible but non-marketable (neither by the market nor by European regulations), and Unfit for human consumption.

Figure 15. Categorisation conducted to analyse FL in orange fields. Source: Zitroladors project. WWF & Espigoladors

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For all these reasons, while there is a high degree of flexibility in establishing categories for FL based on the study's objectives, it is recommended to create at least three basic categories:

- **Edible and marketable.**
- **Edible but not marketable.**
- **Unfit for human consumption.**

A practical example of a field sheet containing the three categories is provided in Annex 8.1 Table 32. As a practical recommendation, it is advised that for each type of crop, determining which products are considered "marketable" should involve discussions with the farmers of the plot, as they are fully aware of the market's requirements, which, as we have seen, can sometimes be more stringent than the regulations setting aesthetic standards and can even fluctuate throughout the seasons. It is also advisable to walk through the plots with the farmers, either prior to or during the quantification process, allowing them to clearly identify what they consider a marketable product and to establish the key parameters for determining whether a product is marketable or not.

As another practical recommendation, collecting samples in the "unfit for human consumption" category can sometimes be more challenging due to the need to handle samples with a high level of rot/decay, which complicates the collection process. (e.g. *Figure 16*). Samples should be collected whenever possible, but always considering the time required to gather those with a higher level of rot in comparison to their specific weight. Given their level of decomposition, their weight is often already very low and may not significantly impact the total weight recorded in this category.

Figure 16. Image of peach loss collected with a high level of decomposition. Source: FOLOU on-field data collection

Another issue or doubt that may arise during the measurement of FL is clearly defining the line between edible and non-edible, particularly in the case of food that appears to be edible but, due solely to having been on the ground for a few days, has been affected by moisture, which may have rendered part of the food less edible. This raises the question of whether to classify it as edible or not.

This manual suggests that food items that were clearly edible and whose "edibility" may have been slightly reduced only due to moisture or similar factors should still be classified as "edible".

As an example, Figure 17 shows a box containing all the oranges classified as "edible and marketable" that were lost from a tree during the harvesting process. It can be observed that some of them have a darker mark on the peel due to ground moisture over a few days. Despite this imperfection, they have been kept under that category because it is believed that just a few days ago (1-2), they would have been considered as such. Therefore, in the

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field, the assessment considers not only whether the fruit is edible/marketable at the moment of measuring its FL but also if there is certainty that it was recently considered as such. This approach helps to gauge the potential for improvement in reducing FL in the operation.

Figure 17. Image of orange losses measured on a tree under the "edible and marketable" category. Source: Zitroladors project. WWF & Espigoladors. ® WWF/Santi Donaire.

However, in cases where there is any doubt as to whether the food was edible in the previous days due to such drivers, it should be categorised as unfit for human consumption. An example of this is Figure 18 , which shows a plum collected during a measurement process where there were doubts about whether it had been edible days earlier, prior to being eaten by a wasp. Due to this lack of certainty, it was classified as "unfit for human consumption".

Figure 18. Image of a plum collected during a loss measurement process and classified as "unfit for human consumption". Source: FOLOU on-field data collection

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In any case, there will always be very specific examples where doubts may arise, as there are numerous scenarios and types of crops. However, the aim is to minimise these uncertainties and establish clear criteria for classifying these losses. If the proposed criteria do not provide sufficient clarity, it is recommended to adopt alternative criteria/classifications. For example, classifications could be based on the primary cause of rejection, without considering whether the items are edible or marketable. It is also advisable to take various photographs of the food products classified within each of the created categories.

Annexes 8.3.1 and 0 contain potential situations where questions may arise regarding the classification of FL for vegetables and fruit, and it is therefore recommended to consult them to review the considerations for these crops.

3.2.3.3 Weighing the identified losses

Once the sampling areas and main categories for discarded foods have been created and located, the process of measuring these foods will be carried out. This process will vary depending on the type of crops, field conditions, harvesting methods, etc. Here we provide guidelines for conducting these measurements for the main crop groups. In general, encompassing all commodities groups, the following aspects are recommended:

- Efforts should be made to measure FL at the pre-harvest, harvest, and post-harvest stages. Obviously, this recommendation is not a "strict rule set in stone," as we will see later. Depending on the different types of food, there are many particularities that make it very difficult or nearly impossible to carry out measurements in some of these stages. In such cases, as is frequently referenced throughout the manual, a pragmatic approach to the issue of FL is pursued. Therefore, in situations where measurement is highly complex or requires substantial, nearly unattainable resources, alternatives will be sought based on the experience of FOLOU case studies.

- While Table 29-PartA and Table 30-PartB, which relate to the basic information to be obtained through in situ measurement, serves as a guide for identifying key parameters to collect and must be contextualised. This means highlighting the diversity and richness of data beyond a single parameter, which will make the diagnosis more comprehensive and accurate in reflecting reality. An example of this can be seen in Figure 19, which summarises a large amount of data collected on FL in oranges, by measuring these losses across different trees within the plot.

  The example depicted in Figure 19 represents one of the quantified orange fields, where categorisation was applied according to four categories, as detailed in the previous section (Figure 15). A single FL figure could be provided, representing the aggregate value of the four categories combined, either through the use of the mean or the median. However, these charts reveal a wealth of additional information. Firstly, the main categories of FL are found in oranges that are neither edible nor marketable (in red), but also in those considered both edible and marketable as fresh produce (in green). Notably, the volume of oranges deemed edible but not marketable (in orange and grey), is considerably smaller compared to the other two categories. This information is highly valuable for the farmer as well. Secondly, the charts illustrate the significant variability in FL across the different trees, ranging from as little as 200 grams to over 3.3 kilograms of loss per tree, depending on the established categories.

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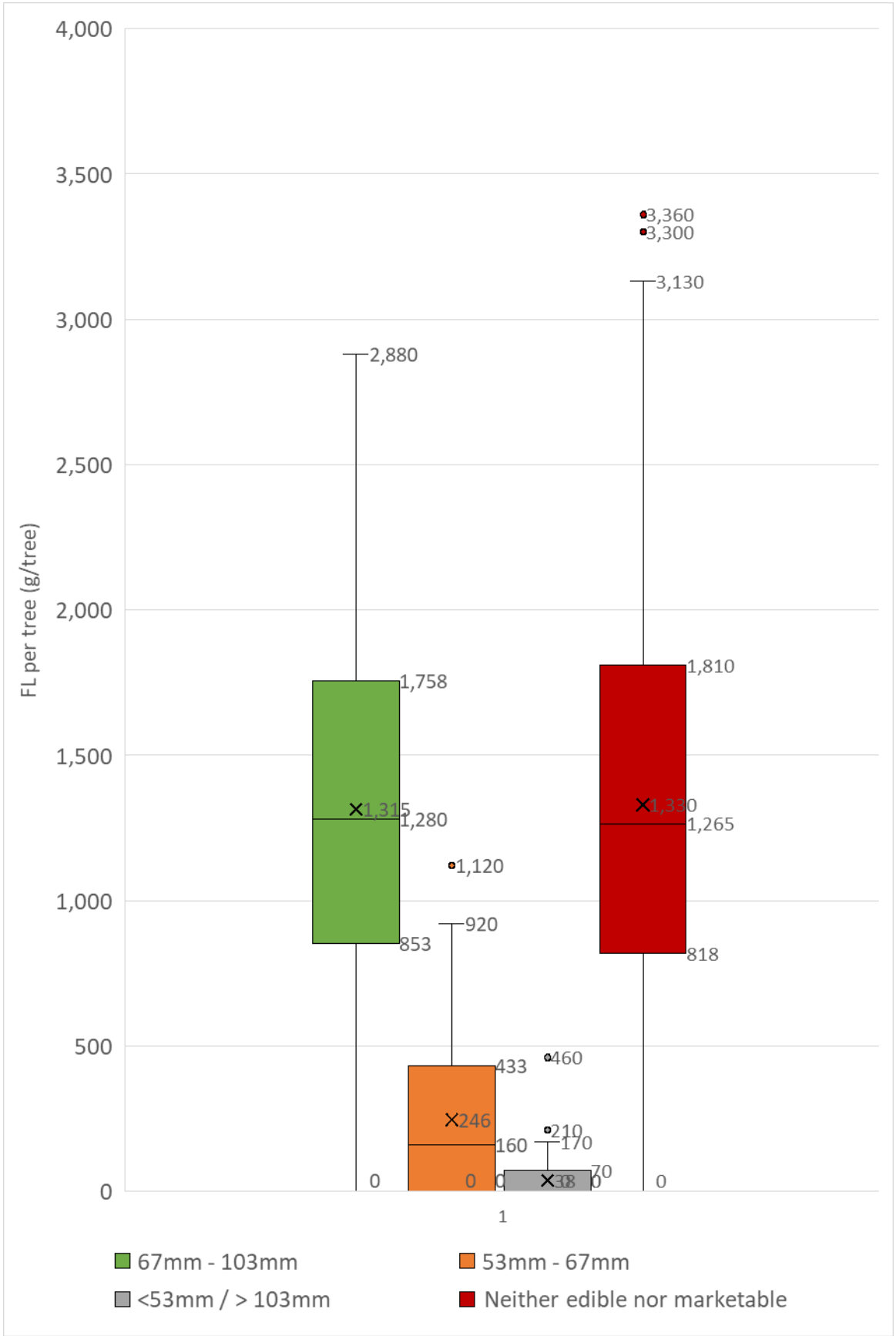

Figure 19. Example of presenting results on FL in a quantified plot (orange crop). Source: Zitroladors project. WWF & Espigoladors

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Additionally, the drivers associated with FL can be further specified, not only at a general level but also specifically within each of the established categories. In the case of the orange example, the main associated drivers could be identified as follows:

- Inedible and non-marketable, in accordance with the coding established under the "reasons" category in Table 29-PartA, and Table 30-PartB, the primary code would be C2 (pests, diseases and phytosanitary issues).
- Edible but non-marketable (calibres <53/>103 mm and 53-67), its primary reason would be linked to category B3 (Marketing and industry standards).
- Edible and marketable (calibre = 67-103). In this case, the main drivers are the dropping of the oranges due to their own weight or gusts of wind, which, once on the ground, are not collected during the harvesting process, or that fall to the ground during the harvesting process itself. Thus, the categories that would most likely align with these drivers would be B15, B16 and C1.

As mentioned in previous sections, analysing the reasons associated with FL measured in the field (Table 30) and comparing them to those identified through interviews/questionnaires with farmers (Table 28), as well as the difference in magnitude measured and reported by the farmer, can provide greater insight into the issues within a plot. In this case, for example, the farmer estimated that the total FL (across all four categories) would be around two kilograms per tree, while the amount measured in the field exceeded this figure by more than double: 4.8 kilograms per tree. Additionally, another significant difference was observed when comparing the associated drivers; although the farmer believed that the main drivers were related to pests/diseases and aesthetic criteria (primarily size), fieldwork revealed that there were losses not associated with these drivers (those related to edible and sellable oranges) that were of greater importance than the loss estimated based on size.

- As an optional consideration, if there is an interest in gaining insights into the discards produced before products have reached maturity—helping to understand or approach the issue defined as production loss, which can impact FL—the interviews/questionnaires being conducted can be used to inquire about this specific issue. In fact, Table 26 includes questions such as "Average yield in the plot (tonnes/ha)," "Estimated yield for this year (tonnes/ha)," and "Main reasons for the differences between average and estimated production" to help address this matter. The difference between the average yield and the estimated yield also encompasses this aspect of production losses. However, thanks to the work carried out by FOLOU's Work Package 3, new technological solutions will be provided to address this issue, along with developments from some of the case studies underway, especially in cereals and root and tubers.

It is essential to specify with each farmer the exact dates of harvest to accurately determine which days in-situ measurements are needed, both for pre-harvest and during-harvest FL. As previously explained, for example in Section 3.2.1, close communication with farmers is crucial in case there are any changes in the harvest dates, so that this information can be communicated to the personnel responsible for conducting the loss measurement processes.

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3.2.4 STEP 4. Plot data extrapolation, analysis, and presentation of results

Once all the information from the previous steps has been collected, both perceived losses through interviews/questionnaires and actual losses through on-site weighing, the main calculations must be carried out to estimate the total FL in the plot.

3.2.4.1 Extrapolation of on-site data to the total plot

In the previous stage, data were obtained from the sampled areas, both in terms of the total FL and according to the distinct categories previously defined (e.g., marketable, edible but not marketable, and unfit for human consumption). These measurements were taken using calibrated scales, and the results were represented in kilograms. From here, we need to extrapolate the loss data from the sampled area to the total cultivable area of the plot. To do this, the following steps must be taken:

- **Step 1:** Calculate the total sampled area in hectares by multiplying the number of random samples taken by the size of each sample. For example, if a sample frame consists of 1 row of 15 meters in length with width of 2 meters, each sample would have a size of 1 x 15 x 2 = 30m². If a total of 10 random samples were taken in a plot, the total sample area would be: 10 x 30m² = 300m² = 0.03 hectares.

  If the unit of sampling used was a certain number of trees, there would be no need to perform this type of calculation.

- **Step 2:** Calculate the total cultivable area of the plot in hectares. This can be done through the following methods:

  a. Information provided by the farmers.

  b. Calculating the number of rows, their length, and spacing. For example, 50 rows with a length of 120 meters and a row spacing of 2 meters. Total cultivable area of the plot = 50 x 120 x 2 = 12,000m² = 1.2 hectares. These calculations are recommended when the plot has a very regular shape (e.g., rectangular).

  c. Using Geographic Information Systems and digital applications that allow for the calculation of plot layouts through satellite imagery. This method is especially recommended for plots with irregular boundaries.

  If it is the total number of trees in the plot, counting can be done using methods "a" and "c". Method "b" would only be applicable if the crop is completely regular, with well-defined and regular spacing between trees.

  Establish the percentage of the sampled area within the total cultivable area of the plot. In this example, it would be (0.03 x 100) / 1.2 = 2.5%. This percentage will be referred to as "significant measurements".

  These approximations are relatively straightforward when conducting sampling based on the number of trees, where it is only necessary to calculate the percentage that the number of sampled trees represents compared to the total plot.

- **Step 3:** Extrapolate the total weighed FL from the sampled area to the total plot. This first involves converting the data into kilograms per square meter based on the number of samples taken throughout the plot. For example, if the sample area is 15 meters per row with a row spacing of 2 meters, and a loss of 7 kilograms is recorded in that frame,

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the loss amount would be 0.23 kilograms per square meter (7 / (15 x 2)). This operation would be performed for all the sample frames. Finally, the following parameters would be analysed for the entire data set:

- Maximum value
- Minimum value
- Arithmetic mean
- Median
- Standard deviation

These parameters allow us to determine whether the sampled areas show relatively similar FL values or not. Depending on the data dispersion, it may be appropriate to use the median or arithmetic mean as the most representative value for the FL in the plot, depending on whether the difference between the two values is significant or not.

- **Step 4:** Repeat this same operation for the different categories of FL previously defined in Section 3.2.3.2. For both the total FL and the losses by category, the category of immature fruit should be excluded from analyses. Table 16 shows an example of the different parameters that should be calculated and considered.

Table 16. Presentation of results for the analysis of FL in a plot. Text in blue denotes an example using fictitious data.

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 loss (kg)**	**Total food loss (kg/m^2)**	**Marketable (kg/m^2)**	**Edible (kg/m^2)**	**Unfit (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

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If the measurements were taken on crops with multiple harvests rather than a single harvest, an adjustment would be necessary. This adjustment would utilise both the actual FL and the perceived FL estimated by farmers.

In calculating pre-harvest, harvest, and post-harvest FL in multi-harvest crops, particularly those with closely spaced harvests (just weeks apart), the main challenge typically lies in calculating harvest losses. This is because pre-harvest losses are considered to occur at the beginning of the harvest cycles, making them similar to those of single-harvest products. Post-harvest losses are generally obtained through records or questionnaires provided by the farmer. For this reason, the calculations necessary for determining harvest losses across different harvests are presented in Table 17 (in addition to which pre-harvest and post-harvest losses should be included if applicable). Thus, Table 17 shows an example of how the calculations would be carried out, starting from actual measurement in the first harvest and extrapolating these results to the rest of the harvests based on the volume collected, with the first harvest as a reference. This operation would need to be repeated for calculating the volume of losses for each of the identified categories (marketable, edible, and unfit). There are several approaches to completing this table, all of which are detailed in Annex 8.3.1..

Table 17. Calculation of total FL in a plot with multiple cuts. Text in blue denotes an example using fictitious data.

Farm ID	27_County_9						
Plot ID	27_County_9_A						
Location	County 9. Region X						
Crop(s)	Tomatoes						
Total food loss							
Sample ID	**Sample size (m^2)**	**First cut (measured) (kg/m^2)**	**2 cut (60% cut 1) (kg/m^2)**	**3 cut (45% cut 1) (kg/m^2)**	**4 cut (40% cut 1) (kg/m^2)**	**5 cut (40% cut 1) (kg/m^2)**	**Total year (kg/m^2)**
1	30	0.138	0.1035	0.092	0.092	0.4255	0.6555
2	30	0.612	0.459	0.408	0.408	1.887	2.907
3	30	0.3	0.225	0.2	0.2	0.925	1.425
4	30	0.15	0.1125	0.1	0.1	0.4625	0.7125
5	30	0.3	0.225	0.2	0.2	0.925	1.425
6	30	0.144	0.108	0.096	0.096	0.444	0.684
7	30	0.084	0.063	0.056	0.056	0.259	0.399
8	30	0.102	0.0765	0.068	0.068	0.3145	0.4845
9	30	0.3	0.225	0.2	0.2	0.925	1.425
10	30	0.342	0.2565	0.228	0.228	1.0545	1.6245

- **Step 5:** This final data should be converted into kilograms or tons per hectare before it can be used to extrapolate losses in the total area of the plot. To illustrate this, let us consider the example presented in Table 16, taking the arithmetic means as reference. Thus, if we wanted to extrapolate the total loss data, we would multiply the plot area (12,000 m^2) by the arithmetic mean value of total losses:

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12,000 x 0.412 = 4,944 kilograms = 4.9 metric tons of losses in the entire plot.

This total quantity can be converted to 4.9 / 1.2 (hectares of the plot) = 4.12 metric tons per hectare of total losses.

This operation would be performed for all identified categories. Table 18 illustrates an example.

Table 18. Extrapolation of the obtained results to the total area of the plot. Text in blue denotes an example using fictitious data.

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)**	**Total food loss (tonnes/ hectare) (tm/ha)**	**Marketable (tm/ha)**	**Edible (tm/ha)**	**Unfit (tm/ha)**
0.03	1.2	4.12	0.82	1.26	2.04

These calculations would be very similar if tree counting is used. To calculate tons per hectare the extrapolation would be completed as follows:

- Total number of trees in the plot.
- Area of each plot in hectares.

Using these factors, the same parameters as in Table 18, would be obtained, and therefore, the rest of the process would be the same. For example: if there are 13.5 kilograms of total losses on one tree as the arithmetic mean in the plot. This figure has been obtained in a plot of 110 trees, with an area of 0.17 hectares, resulting in an average figure of 8.8 metric tons of losses per hectare.

These final figures can also be presented as percentages with respect to the total harvested production or even the portion of that harvested volume that ends up in the market. To obtain these parameters, data from the farmers can be used or even specific on-site studies, as was done in Austria and Germany[24]. The ultimate goal is to achieve a percentage with respect to one of these two parameters. Continuing with the same example used in Step 5, if the average production is 65 metric tons per hectare, FL figures can be correlated with the final harvest obtained through three possible indices:

- First, the FL Index recommended by FOLOU:

$$FL\ Index = \frac{FL}{Total\ harvested + FL} x\ 100$$

This index allows for the calculation of what percentage of the total losses generated (pre-harvest, harvest, and post-harvest), in relation to the total harvest produced, is attributed to losses and what percentage is associated with the total harvest. For example, in a field of lettuce, 8% represents FL, while the remaining 92% refers to the harvested amount. Applying this index to the example being utilised, the following data would be obtained (Table 19).

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Table 19. Results obtained for plot losses as FL indices with reference to the 2023 production. Text in blue denotes an example using fictitious data.

Farm ID	27_County_9				
Plot ID	27_County_9_A				
Location	County 9. Region X				
Crop(s)	Tomatoes				
Total food loss (tonnes)	**Total harvest 2023 (tonnes)**	**Total FL index (%)**	**Marketable losses index (%)**	**Edible losses index (%)**	**Unfit losses index (%)**
4.9	76.3	**6.03**	**1.29**	**1.93**	**3.05**

- Secondly, the following index can be applied:

$$\frac{FL}{Total\ harvested} x\ 100$$

This parameter indicates the total amount of FL (pre-harvest, harvest, and post-harvest) in relation to the percentage of the total harvest achieved. For example, in a banana field, the recorded losses amount to 12% of the total production obtained.

In this case, the percentage of total losses with respect to this production would be: (4.12 x 100) / 65 = 6.34%. These percentages can also be calculated for all established categories. Table 20 summarises all the calculated figures in this example.

Table 20. Results obtained for plot losses as percentages of the 2023 harvest. Text in blue denotes an example using fictitious data.

Farm ID	27_County_9				
Plot ID	27_County_9_A				
Location	County 9. Region X				
Crop(s)	Tomatoes				
Total food loss (tonnes)	**Total harvest 2023 (tonnes)**	**Total food loss (% total harvest)**	**Marketable losses (% total harvest)**	**Edible losses (% total harvest)**	**Unfit losses (% total harvest)**
4.9	76.3	**6.42**	**1.31**	**1.97**	**3.15**

- Lastly, an index is proposed that, according to FOLOU's criteria, is most appropriately represented as FL relative to total production. This is based on the understanding that a field, farm, or pond produces not only what is harvested but also encompasses other factors captured under the terms “food loss” and “production losses”:

$$\frac{FL}{Total\ harvested + FL + Production\ losses} x\ 100$$

$$(Total\ production = Total\ harvested + FL + Production\ losses)$$

This index is logically the most complex to calculate, as it also requires data on production losses. However, to include it in the example, let’s assume we have

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managed to calculate it, and the value obtained is 5.8 tons of tomatoes classified as production losses.

Table 21. Results obtained for plot losses with respect to the total 2023 production. Text in blue denotes an example using fictitious data.

Farm ID	27_County_9		
Plot ID	27_County_9_A		
Location	County 9. Region X		
Crop(s)	Tomatoes		
Total food loss (tonnes)	**Total production losses (tonnes)**	**Total harvest 2023 (tonnes)**	**Total food loss with respect to total production (%)**
4.9	5.8	76.3	**5.63**

For the process of quantifying FL, especially when determining sampling areas, calculations, and extrapolating figures to the total area of the plot, there are already digital tools available that can assist many users in obtaining these results. Notably, the Global Farm Loss Tool created by WWF and endorsed by WRI for 10x20,000x30 allows for the automation of many of these calculations, visualising them in real-time and storing all information on a web-based platform. The tool is available in Spanish and English and will include Scope 3 emissions calculations by the end of 2025.

Within the framework of the FOLOU project, an Excel tool has been developed to facilitate the calculation and extrapolation of data from the samples to the entire plot (forthcoming on CORA).

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3.2.4.2 Estimated cost for food loss measurements

During the course of the FOLOU project, information regarding the costs of quantification processes of FL, specifically for the fruit and vegetable sector, has been collected. Particularly, key parameters that should be considered when planning a FL measurement are the following:

- **Human resources:** how many people are necessary to do the quantification; how many technicians and non-experts are needed; time of planning and data collection in the field; time for data analysis; time of traveling to the field;
- **Transportation costs**: depending on if the vehicle for the data collection is owned by the company, or it needs to be rented; eventual tolls; gasoline costs;
- **Material and equipment costs**: these costs are mostly fixed, as the main costly materials needs to be bought every couple of years. Here we include: a portable scale; sampling tools (e.g. knife, scissors, etc.); boxes; gloves; identification aprons. The main cost here arises from the scale.

According to the experience developed by Espigoladors in conducting on-field measurements, the time and human resources required for sampling are the following: for a field of about 700 m2, sampling its 10%, two people and about 1- 1,5 hour would be necessary to sort and weigh the sample by the three driver categories. Subsequently, 30 minutes would be necessary to input the collected data into a software (e.g. Excel), process the data and extrapolate them for the entire field and the region.

For other food commodities costs' specificities, please consult Annex 8.3.

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4 Extrapolating food loss data from farms to an entire territory

The objective of this chapter is for the reader to understand how to process the food loss data collected from the sampled farms and extrapolate the results to the entire territory under study.

Target audience: public administration and researchers

4.1 Extrapolation of the calculated figures per plot to the total estimated sample in a territory

As discussed in previous chapters, this on-site measurement has been conducted in several plots. These plots must encompass a representative sample of the economic activity we are analysing (e.g., losses in tomato crops in Region X).

To perform this extrapolation process, we must have previously obtained the information outlined in Section 3.2 for each of the identified plots. Following this, a similar operation to the one summarised in Table 18 will be conducted, incorporating the average/median information from each quantified plot and the calculations established in Table 16.

Table 22 shows an example of the calculated and obtained results, continuing with the example of tomato cultivation in Region X. It can be observed that the table header now represents the entire economic activity, not just the plot ID, with both the associated NACE code and its CPA. This would be the result of the total sample collected, used to calculate data for all losses in tomato cultivation in Region X.

In fact, whether through NACE Classes or 5 or 6-digit CPA coding, a decisive first step can be taken in quantifying FL in a territory by determining which groups will be used for the extrapolation of data.

Three possible scenarios would be considered:

1. Obtaining a single FL index (Extrapolation of on-site data to the total plot 3.2.4.1) and extrapolating that index to all crops classified as "Growing of cereals (except rice), leguminous crops and oil seeds.".
2. Calculating 9 different loss indices based on the categories listed in the "CPA Approach," with each index having its own extrapolation based on the specific crop types present in each territory. In this case, there would be 8 categories instead of 9, as the category "01.11.5 Cereals straw and husks" would be excluded since it is not considered a food.
3. Developing 29 FL indices according to the categories listed in the column titled "CPA Approach 2," with each category having its own extrapolation process. In this case, there would actually be 28 categories, as a non-food product type named as "01.11.50 Cereals straw and husks" would be excluded.

The 5-digit Classification of Products by Activity (CPA) approach is initially considered the scenario that could provide sufficiently rigorous figures without being excessively time and resource-consuming for calculating FL in a territory. However, if the use of CPA codes is not feasible, at least the 4-digit NACE codes should be used.

In fact, there is even the possibility of a "mixed approach" where, depending on the characteristics of each territory, the most prevalent crops in terms of production and/or area are selected and identified using the 5-digit coding, unless there is a need to differentiate them from other similar crops of great interest to the territory, in which case the 6-digit

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coding would be used. Thus, once the main crop types are identified and marked with the 5 or 6-digit codes, a more general category can be created to group several crop types, yielding data of lower quality but of lesser importance to the territory.

Table 22. Presentation of the results obtained for all quantified plots on-site. Example of tomato cultivation (CPA 01.13.34) in Region X. Text in blue denotes an example using fictitious data.

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)	Total food losses (tm/ha)	Marketable (tm/ha)	Edible (tm/ha)	Unfit (tm/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

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4.2 Estimation of losses for a specific economic activity based on the sample data collected across the territory

Finally, the total cultivated hectares in the territory must be calculated to enable extrapolation. For the example of tomato cultivation in Region X an average (which is exactly the same as the median) of 4.44 tons per hectare was obtained. As the total tomato cultivation area in Region X is 230 hectares, the total tomato losses would amount to 4.44 x 230 = 1,022 tons of losses in tomato production in Region X during 2023. These same results will be calculated for each of the established categories.

It's important to note that for extrapolation processes, if there are disparities between the mean and median, it's considered more rigorous to use the median over the mean, especially in contexts of few observations and/or notable divergences in the figures that could arise from samplings.

Table 23 presents the final results obtained as an example, where the breakdown of quantities based on the three main categories created provides initial insights into the drivers of this waste. This information will be presented alongside the analysis of perceptual data provided by the farmers and a review of relevant literature, together offering a comprehensive view of the entire issue.

Table 23. 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. Text in blue denotes an example using fictitious data.

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 (tm)	**Marketable (tm)**	**Edible (tm)**	**Unfit (tm)**
1,022	175	294	552

Sometimes this data may not be available, making these calculations challenging. One possible approach would be to calculate based on the number of registered tomato farms in Region X and their average size. For instance, if there are a total of 27 farms with an average size of around 3.5 hectares, the total losses would amount to 27 x 3.5 x 4.44 = 419 tons of losses. While this approach does mean assuming higher errors, it enables us to obtain loss figures for specific economic activities within a territory. These figures serve the following purposes:

- To compare the obtained results with other specific loss studies in the same territory or even outside its borders, thus creating synergies between studies and generating a broader and more comprehensive view of the problem.
- To contribute to the information on FL in a territory, as mentioned earlier in the manual, such as at the beginning of Chapter 2.3.2 where it is stated, "we cannot compare apples and pears", a comprehensive understanding of the issue will require conducting similar studies for other predominant crops in the region. This approach will help in gradually assembling the complete picture.

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4.2.1 Additional strategies to extrapolate data

Another approach, albeit with a lower level of reliability, can still help to provide an indication of the magnitude of FL in a given territory. This is particularly useful in the early stages, when it is not possible to carry out in situ quantification across all the food categories that one would ideally like to assess. In such cases, field studies conducted in neighbouring or nearby regions to the area under study can be used as a reference.

This could allow, for example, Region X, which we have presented as a case study, to use its studies on tomato losses as a reference for Region Y. In this way, by taking the main figures from Section 3.3 as a reference and applying the same process used for the extrapolation in Section 4.1, the calculations could be adapted to Region Y.

This could help foster synergies between neighbouring regions and territories, thereby improving resource efficiency. One region could focus in depth on measuring and analysing a specific food category, while another region could carry out similar work on a different category of shared interest, and then exchange data.

In this way, it would at least be possible to obtain estimates of the scale of the issue in a given region for two different food categories, one with a much higher level of reliability based on in situ work within the region, and another with a lower level of reliability derived from a nearby region. Nevertheless, this would represent a step forward in understanding a shared problem. Such collaboration would enable a more comprehensive and holistic diagnosis across territories, rather than operating as isolated "knowledge silos" with a more limited view of the issue.

Finally, this manual also aims to provide a way to advance the understanding of FL in a given territory **in cases where all available information comes exclusively from questionnaires and interviews**, which is a common situation in some countries.

In this regard, the improvement pathway proposed in this manual is not limited to providing only aggregated final data on FL, for example, for the entire productive sector of a country derived from such questionnaires and interviews, but also to include disaggregated data tables by food type. This can be achieved, in particular, through the use of NACE and ISIC codes, so that the information can be presented by food category and also serve as a basis for comparison and cross-checking with other territories.

For instance, imagine information similar to that presented in Table 24 coming from Region Z, with all data aggregated but disaggregated according to NACE classes, where farmers have responded through a series of survey forms:

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Table 24. Presentation of FL results obtained through questionnaires, disaggregated by food type. Example from Region Z. Text in blue denotes an example using fictitious data.

Crop(s) covered for food loss ratio		Tomatoes, apples, pears and lettuces				
Territory		Region Z				
Type		Questionaries collected				
Year		2025				
NACE Class	**CPA Code**	**Number of surveys collected (n)**	**Total food loss (tm/ha)**		**Standard deviation (tm/ha)**	**FL Index (%)**
			Median	**Average**		
01.13 Growing of vegetables and melons, roots and tubers	01.13.3 Other fruit-bearing vegetables / 01.13.34 Tomatoes	32	1.20	0.75	1.31	1.63
01.24 Growing of pome fruits and stone fruits	01.24.21, Pears	19	1.01	2.47	3.02	3.35
01.24 Growing of pome fruits and stone fruits	01.24.11 Apples	14	2.03	3.79	4.9	5.15
01.13 Growing of vegetables and melons, roots and tubers	01.13.14 Lettuce	23	4.01	5.91	4.03	8.04

Logically, this is an example of a table, which may include a more detailed level of disaggregation (for example, percentage estimates of the categories edible/marketable, edible but non-marketable, and inedible).

They may also contain less information; however, it is considered highly useful to know both the percentage of losses contributed by each food type and a dispersion analysis of the data, that is, to assess whether there is significant variability in farmers' responses depending on the crop or not

In addition, this example illustrates how, for instance, Region X may be interested not only in the overall FL index in primary production in Region Z, but also, for example, in the loss rate for tomato crops. This can be done by comparing information obtained through in situ measurements (Region X) with data collected via questionnaires (Region Z).

Within territories that assess FL exclusively through questionnaires, and as a further step towards improving accuracy within the constraints of available resources, it is recommended to carry out a limited number of in situ measurement exercises as "spot checks" within farmers' fields. These measurements can be used to assess the differences between the losses reported through questionnaires and those obtained through direct in situ measurement.

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In this way, it may be possible to calculate a potential correction factor, as FAO concludes that questionnaire-based approaches tend to underestimate FL. This distortion could therefore be partially adjusted by applying a correction factor derived from these limited in situ measurements [44].

Naturally, the greater the number of in-situ measurements, the more robust the conclusions will be. However, even under significant resource constraints, conducting at least 2–3 in situ measurements for a given food commodity can provide useful insights, generating information similar to that presented in Table *25*.

Table 25. Comparison of FL results obtained through weighing and questionnaires across three plots from Region Z. Text in blue denotes an example using fictitious data.

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 Z (3 farmers)					
Type	Sample measured and questionnaires collected					
Total food loss (tm/ha)						
ID	**Weighting**			**Surveys**		
	Median	**Average**	**Standard deviation**	**Data**	**Median**	**Average**
14_County_3_J	1.2	1.26	0.58	0.60		
31_County_1_C	1.1	1.34	0.53	0.75		
7_County_5_A	1.5	1.76	0.81	0.85		
Total	1.34	1.45	0.28		0.75	0.733
Comparison of the means (%)	49.5					
Comparison of the medians (%)	44.0					

As can be observed, the measurements obtained through questionnaires exhibit an underestimation of approximately 44% to 49.5%, depending on whether the mean or the median is used, compared to the measurements obtained in the same plots through weighing. Thus, the discrepancy between survey-based and measurement-based approaches affects not only the aggregate level (mean losses), but also the central tendency of the distribution (median losses). This indicates that surveys do not merely underestimate extreme or sporadic loss events but tend to systematically shift the entire distribution of reported losses downward. As a result, both the "typical" loss level and the overall magnitude of losses are underestimated, suggesting a structural bias rather than isolated reporting errors.

Thanks to these calculations, the underestimation identified in the analysed surveys can be translated into a correction factor and applied to the full set of survey data summarised in Table 24. In the case of tomato FL, the survey results yielded a mean of 0.75 tonnes per hectare and a median of 1.20 tonnes per hectare.

By applying the correction factors of 49.5% for the mean and 44% for the median**, the adjusted estimates would be 1.49 tonnes per hectare based on the mean and 2.14 tonnes per hectare when using the median as the reference.**

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5 The use of emerging technologies to support and enhance the measurement of food loss and production losses

5.1 Emerging technologies to facilitate the measurement of food loss

5.1.1 Introduction

Direct measurement of food losses in primary production systems has, to date, relied on labour-intensive field-based procedures. The sampling approaches employed often suffer from uncertainties due to the non-random spatial distribution of losses within fields, making upscaling difficult. Computer vision, particularly the use of high-resolution RGB cameras mounted on drones or tractors, offer a practical and scalable alternative. This manual provides guidance on implementing such methods in the field. Vision-based measurement systems rely on capturing images of crops and analysing them to detect, count, and classify losses. Drones can cover several hectares in a single flight, providing rapid and relatively low-cost assessments. Tractor-mounted systems offer an alternative for continuous monitoring during field operations. These approaches allow full-field coverage, reducing sampling bias and improving accuracy.

5.1.2 Equipment and Setup

Crop Suitability

This method is most effective for crops that are clearly visible above ground, such as most full-field vegetables (lettuce, cabbage, cauliflower, …) or fruits (e.g. apples, oranges, grapevine, …). It is not suitable for root crops or very small grains. In FOLOU, detection models are developed for a few crops (cauliflower, lettuce, red apples, oranges). For other crops, the models must be trained separately, and new datasets from multiple fields should be collected to train or adapt detection models (see further).

Timing of Data Collection

Actual losses can be quantified either during the harvest (tractor-mounted camera) or immediately after harvest (e.g., in drone-based applications). Data collection should occur at least immediately after harvest, to track the amount of non-harvested crops (either left on the plant or dropped on the ground). However, ideally, a pre-harvest assessment should also be performed, to quantify the actual yield and possibly also the detect damaged produce.

Choosing the sensor

Tractor-based systems require the integration of high-resolution cameras and precise localization systems, ensuring stable image acquisition. For many crop types, tractors are routinely used throughout the production cycle, and in some cases even during harvesting, making it possible to perform image acquisition and analysis simultaneously with ongoing field operations.

In case of a drone application, a wide range of modern drones equipped with RGB cameras can be used for data collection. The type of drone required typically depends on the required ground sampling distance (spatial resolution), the scale as well as the type of crop. For most field vegetables, for instance, a resolution of 0.5 cm is already sufficient; as the

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crops are low and the fields typically relatively flat, a miniature consumer-grade drone can already be sufficient to give images. For orchard crops, however, the distance between the drone and the canopy needs to be larger due to safety reasons, and the resolution needs to be higher – often at mm level. Here, more advanced zoom cameras on more professional drones seem more appropriate. Alternatively, drone service providers can be hired.

For most applications, it is useful to have precise GNSS information. This is a given when working with drones. For tractor-mounted sensors, GNSS information can either be derived from a separate sensor, or from the onboard GNSS system; here, a correction per camera for the viewing angle and the actual position relative to the sensor should be performed. RTK or PPK technology gives the best results, and is preferred when working with individual images, such as for most tractor-based applications, or, in the case of drones, when no Ground Control Points (GCPs) are available [61]. When GCPs are available, on-board RTK or PPK is not strictly needed.

Data Collection Strategies

Several approaches are possible. Both tractor and drone-based systems can be used to collect either continuous video or a large number of individual images. In the case of tractors, images are typically analysed separately. In the case of drones, the standard approach is to collect images with high overlap, typically for converting the individual images to detailed maps of the entire field (georeferenced orthomosaics) with structure from motion software. However, images can also be collected as isolated samples within a field, with very little or no overlap between the images, in which case they are typically processed individually. This significantly reduces flight time as well as the amount of data to process. For a detailed approach on how to collect drone data and for optimising flight patterns and flight settings, we refer to the background given and guidelines formulated by Maes (2025) [62], in particular on high resolution RGB data.

Data processing strategies

Next, the data need to be processed. This can either be done through manual processing, or in a fully automated process, normally relying on deep learning. Although manual processing requires relatively little expertise and can be an option in case of relatively small and unique datasets, it is very labor-intensive. Hence, for larger datasets or several smaller datasets, an automated method, relying on deep learning, is preferred.

Building a deep learning method

Data were collected on selected plots, at specific production stages, and under targeted agronomic conditions, enabling reliable ground-truth extraction for model training and performance assessment in real field conditions. The current focus remains on validating the methodology within representative contexts, rather than developing fully generalized multi-crop models.

To generalize the solution and its models to other types of fruits or vegetables, new data collection and preparation will be required. This extension will involve expanding both the diversity of crops and the range of field conditions considered, in order to improve model robustness and transferability. Some important recommendations for data collection and model development include:

If possible, collect data in a variety of conditions. For instance, methods tend to be more robust if the training dataset contains data collected in sunny and in shady conditions.

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To build sufficiently robust methods, data need to be collected of sufficiently large and sufficiently diverse datasets. We recommend collecting data in at least five different fields.

Keep a dataset of at least one field as a independent test dataset, in order to evaluate the performance of the model in unseen conditions.

For commodities very similar to the developed methods (similar fruits or vegetables), the existing models can be adapted using transfer learning, reducing the need for extensive coding and large datasets. This will still require a relatively large number of labelled datasets.

For other more diverging commodities, new deep learning methods will need to be developed. This will normally require a larger number of labelled data, as well as the model development. This can be done with publicly available architectures, such as the YOLO architecture.

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Case study 1. Measuring food loss in vegetable crops

The present work, led by Dilepix (France), developed and evaluated two complementary approaches for field-scale food loss assessment, addressing both manual quantification support and fully autonomous estimation.

1. Decision-support for manual quantification

The first approach focused on improving manual food-loss estimation by reducing sampling limitations through field homogeneity analysis. Variability within fields was quantified using the coefficient of variation (CV) of remaining vegetable size and distribution. Spatial mapping of heterogeneity was then introduced to identify zones with common characteristics. This decision-support tool helps to guide field sampling by translating spatial variability into interpretable visual information. It reduces sampling bias and improves the reliability of manual assessments by weighting global results according to zone characteristics, in particular the area of each zone relative to the total targeted field area. Preliminary results from recent tests show that guided sampling can reduce estimation error by up to 60% compared to random manual measurements.

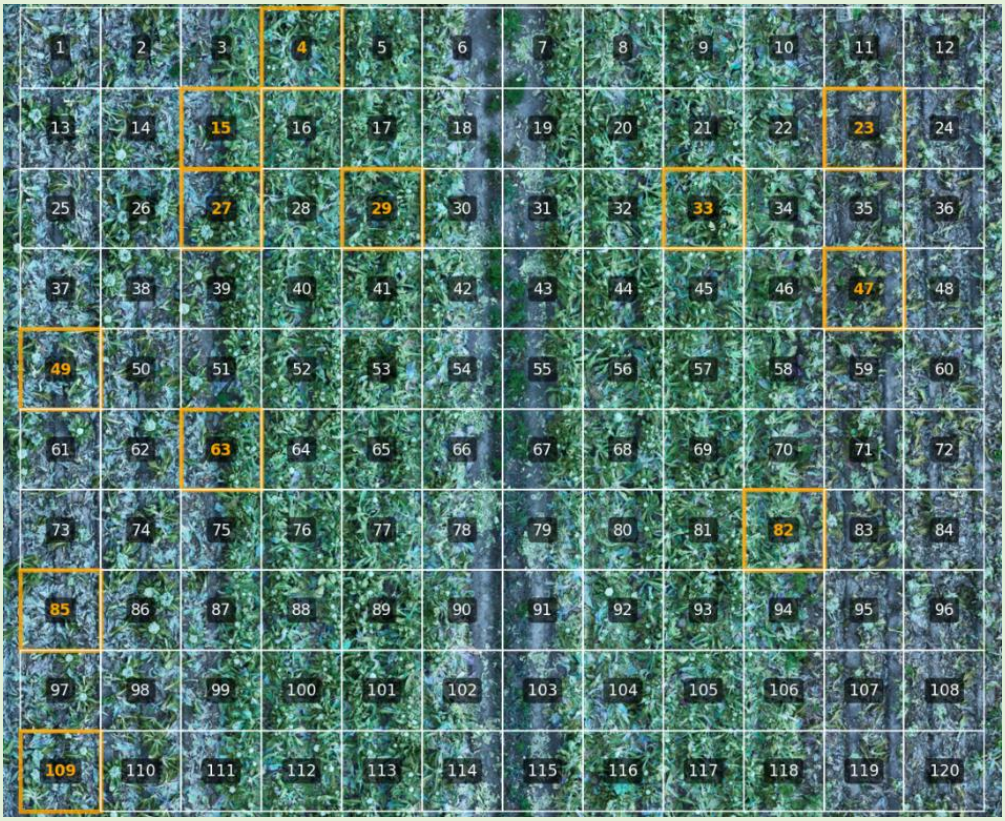

Figure 20. Guided sampling using field homogeneity analysis

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2. Autonomous food loss quantification

The second approach, which represents the main objective, focuses on autonomous estimation of food losses. It relies on object detection to identify remaining vegetables in the field and represent them through bounding boxes. Since food loss is expressed in mass (kg/ha), these spatial measurements are converted into weight estimates using crop-specific allometric relationships derived from manually annotated data and field sampling. Several modelling strategies were explored to relate bounding-box size to individual crop weight. Preliminary results were obtained by comparing autonomous estimates with manual measurements for lettuce and cauliflower fields, demonstrating the feasibility of the approach. On recent tests, the automatic approach achieved up to 77% accuracy compared to ground-truth gleaning measurements.

Figure 21. Remaining vegetables detected (bounding boxes) on a cauliflowers field

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Case study 2. Assessing losses in apples and oranges

This case study, led by Universiteit Gent, explores how drone imagery and deep learning can be used to assess losses in apple and orange orchards. Compared with vegetable crops, fruit orchards present additional challenges because fruits can be partially or fully hidden by leaves, branches, shadows, or other fruits, making occlusion one of the main challenges in this case study. An optimal viewing angle, or combination of viewing angles, therefore needs to be defined minimizing the occlusion effects.

High-resolution RGB images were acquired using a DJI M 350 RTK UAV equipped with a DJI Zenmuse P1 full-frame camera, flying at approximately 12 m above the canopy from three viewing angles: 90°, 70°, and 50°. These complementary views improve fruit visibility and reduce missed detections caused by occlusion. Deep learning models were developed to detect and classify visible fruits, including damaged, fallen, and unharvested fruits. By combining detection from the different angles and linking fruit counts with field measurements such as average fruit weight, the approach supports the estimation of food losses.

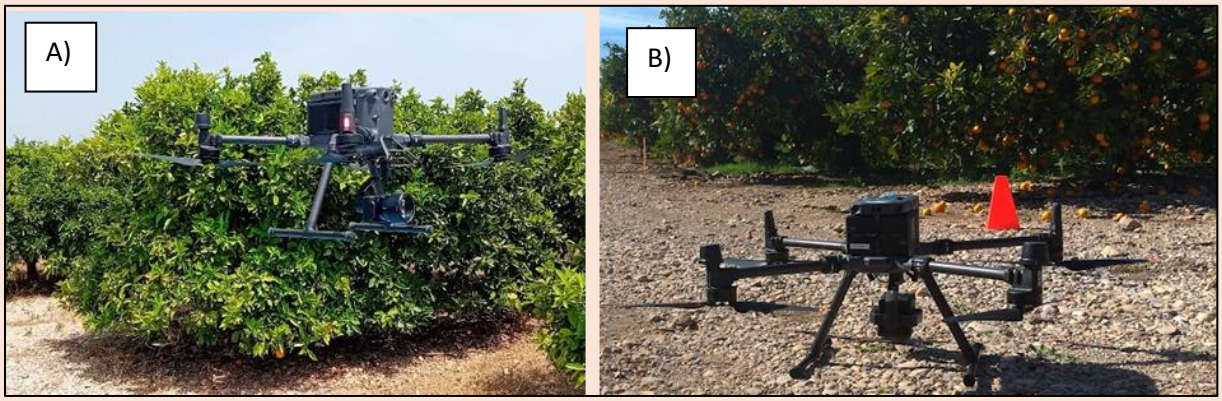

Figure 22. M350 RTK drone in orange orchards: A) Sony RGB camera and B) LiDAR sensor

Overall, this case study demonstrates the potential of high-resolution RGB sensors, multi-angle UAV acquisition, and deep learning models to support fruit loss assessment in orchards.

Figure 23. Example of apple detection results from the tested model

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5.1.3 Challenges and Limitations

As mentioned, this method is only suitable for crops that are visible; for below-ground crops (tubers), a different methodology would be required.

The use of allometric relationships in this context, as presented in Case Study 1, is limited by the inherent variability of biological systems and field conditions. The relationship between visible size (e.g., bounding-box dimensions) and actual crop weight is influenced by multiple factors such as cultivar differences, growth stage, and environmental conditions. As a result, allometric functions derived from limited sampling may not generalize well across different fields or production contexts.

In addition, occlusions—where fruits or vegetables are partially hidden by leaves, branches, or other fruits—along with variable viewing angles and segmentation inaccuracies in the detection stage, can introduce errors in the estimated size, which then propagate into the final weight estimates. These uncertainties can lead to systematic bias, particularly when extrapolating beyond the conditions under which the calibration data were collected. In this direction, a correction factor is required and is currently under development for Case Study 2 (apples and oranges).

For both case studies, achieving a generalized and robust solution requires high-quality labelled datasets that capture sufficient variability across crops, growth stages, and field conditions. However, the creation of such datasets is resource-intensive, as it relies on extensive manual annotation and careful field sampling to ensure reliable ground truth. In addition, environmental factors such as lighting variations, shadows, and weather conditions can significantly affect image quality and, consequently, the accuracy and robustness of the detection models.

From a practical point of view, the developed solution must be adapted to the specific characteristics of the target crops as well as their typical in-field operational practices. Indeed, crop type, cultivation system, and harvesting logistics can strongly influence both the feasibility of data acquisition and the choice of sensing platform. As a result, appropriate data collection and processing strategies need to be defined on a case-by-case basis, ensuring compatibility with real field constraints while maintaining the reliability and usability of the generated outputs.

In addition, cost represents a key factor for real-world deployment. Hardware requirements, field campaigns, and the need for expert input can significantly increase operational expenses, making it important to balance model performance with overall system affordability and scalability.

5.1.4 Conclusion

Vision-based technologies provide a promising approach for direct FL measurement in the field. By combining efficient data collection with automated analysis, these methods can significantly reduce costs and improve accuracy compared to traditional approaches. Wider adoption will depend on further development of standardized protocols and user-friendly tools.

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5.2 Emerging technologies to facilitate the measurement of production losses and other uses and improvements

The above-mentioned technology provides a direct measurement of primary food losses for fruit and vegetables. In the FOLOU project, other technology-based applications are also under development. Although they are less suitable for wide-scale implementation, we here provide a very brief overview of these methods:

Case study 3. Production loss estimation combining satellite or drone-based remote sensing with crop growth models

This study, led by UNIVPM, evaluates the DSSAT-CERES-Wheat model to simulate durum wheat growth and yield gap incorporating Leaf Area Index, either from drone data or from satellite data, across three Mediterranean environments under climate change, supporting adaptation strategies. The crop growth model, calibrated for the Tirex variety using long-term data and validated across sites in Northern, Central, and Southern Italy, showed strong performance for yield, biomass, and phenology. Climate change scenarios project yield reductions in the near future, especially in the North, while some increases occur in the far future, partly due to CO_2 fertilisation effects.

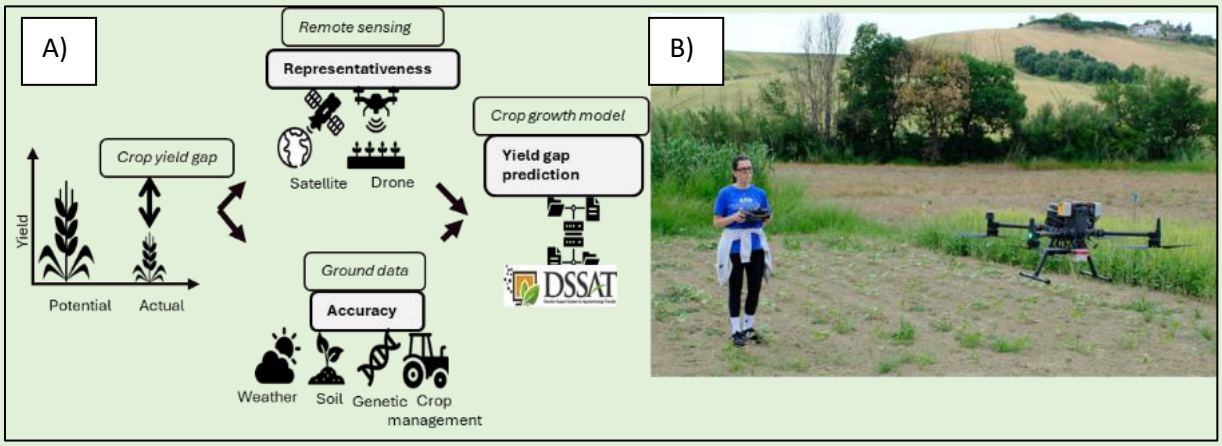

Figure 24. A) Integration of DSSAT crop model to support the estimation of yield gap from heterogenous collected data. B) Drone to acquire multi-spectral images on the FOLOU – UNIVPM fields.

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Case study 4. Avoiding production losses in aquaculture using machine vision-based embryo sorting

The research, led by UNIVPM, aimed to develop and validate a technological automated vertical incubator prototype, equipped with vision technology and robotic sorting equipment. The functional prototype is able to gently lift the embryos without causing any damage, to image and recognise infected embryos in real-time and to remove the non-developing or infected ones. The prototype of the vertical incubator was developed and efficiently lifted the embryos to the sorting area in which the cameras discriminated bad and good ones with an overall accuracy of 94% using a deep learning algorithm. This prototype could improve the number of embryos that achieve the eyed stage up to 5%, thus improving the productivity of trout farms.

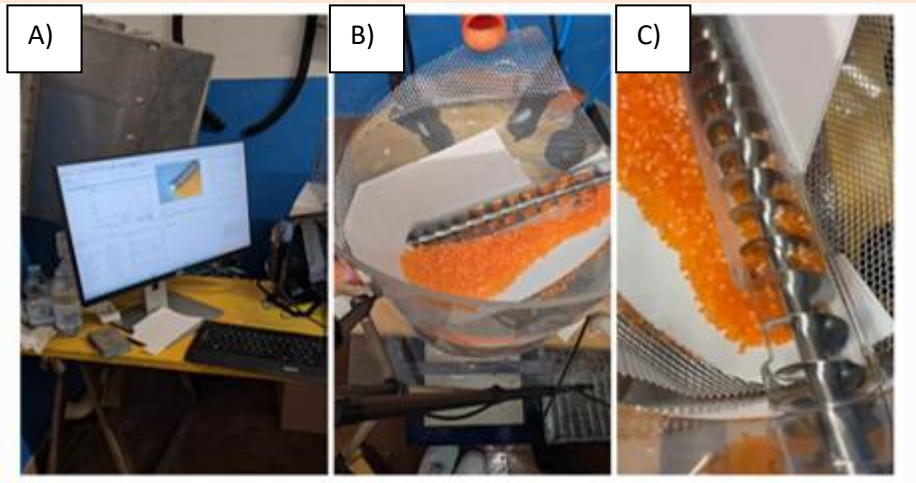

Figure 25. A) Acquisition of images to classify the embryos. B) and C). Details of developed system to lift embryos.

Case study 5. Reliable accounting of food losses through blockchain technology: use case in Mussels

The purpose of this research, led by UNIVPM, was to provide a prototype method that allows customers to quickly scan a food product and retrieve reliable automated information of the food losses during the growth, using blockchain technology.

To ensure this information is reliable, the system uses **blockchain technology**, which serves as a secure, tamper-proof digital record. This ensures that the data shown to consumers cannot be altered or manipulated. Different user types access the system via a web application. The application processes and verifies the data before storing key information on the blockchain. While the technical steps are complex, the goal is straightforward: guarantee that the information provided is accurate and trustworthy.

All data about mussels — such as production details and food losses — is stored in a database, allowing the system to maintain a complete, easily accessible record, while the integrity proof is stored on the blockchain. This combination of blockchain and traditional data storage ensures transparency and efficiency while keeping costs low.

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Case study 6. Leveraging Internet search and social media data to predict future food demand

Demand forecasts and supply information can be analysed to identify potential food surplus and quantify food loss. This approach benefits from an increase of accuracy of consumption predictions, which could be achieved by exploiting data from online activity. With that purpose, search queries and posts from social networks have been introduced into consumption models for different commodities and forecast horizons.

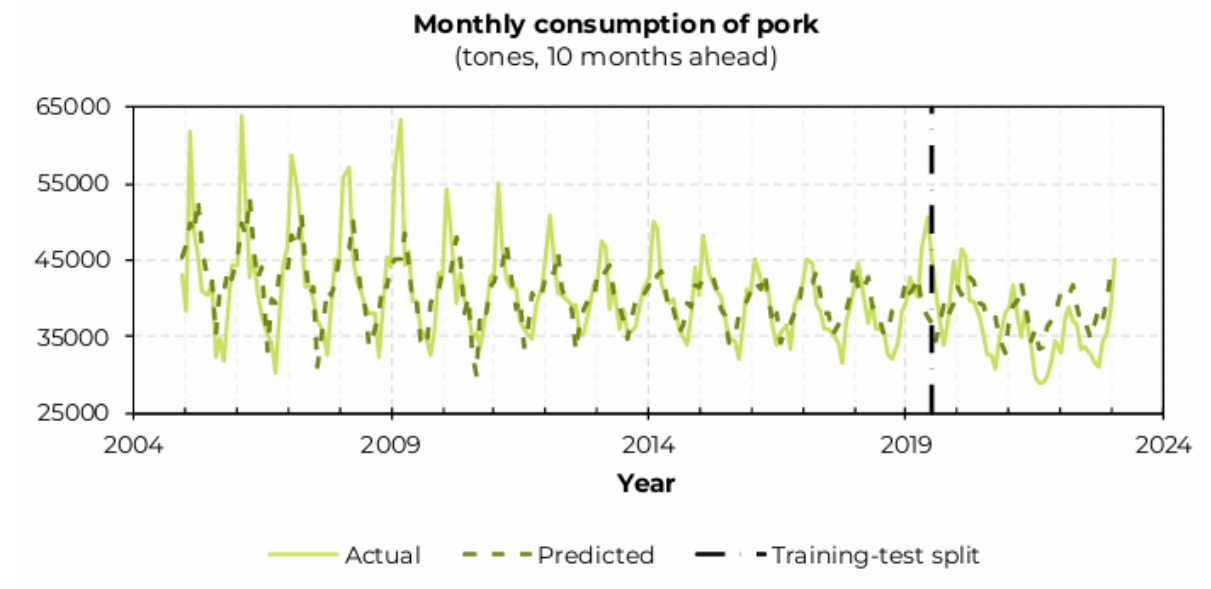

Figure 26. Actual and predicted values for monthly consumption of pork ten months ahead

Figure 26 shows how monthly pork consumption can be forecast up to ten months in advance by combining traditional consumption data with online signals such as Internet searches. The solid line represents the actual pork consumption, while the dashed line represents the model's predicted values. The vertical dashed line marks the training-test split: data before this point was used to train the model, and data after it was used to evaluate how well the model performs on unseen future periods.

In this case, the predicted line broadly follows the same seasonal behaviour as the actual consumption line, suggesting that the model captures the main consumption patterns. Although some short-term peaks and drops are not perfectly predicted, the forecast provides useful information for planning because it indicates the expected direction and magnitude of future demand.

In order to improve commodity consumption forecasts and support food loss prevention, online activity can be used as an additional signal of consumer behaviour. Previous sentiment analysis work was based on X data, but with no enough temporal coverage and closing of the source, it was required to change the data collection strategy. Reddit was therefore selected, since it contains large volumes of user-generated discussions about food, recipes, ingredients, prices, preferences, and consumption habits.

The first step is to check whether the data provides enough temporal coverage. The annual volume of retrieved Reddit data shows that the dataset covers the full 2013-2023 period with relatively stable yearly volumes. This is important because a consistent time series allows sentiment trends to be compared over time and potentially aligned with commodity consumption data.

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The distribution by subreddit also helps confirm that the retrieved data is relevant to the food domain. Most observations come from broad communities such as *cooking* and *food*, which capture general consumer conversations, while more specific subreddits such as *AskCulinary*, *recipes* and *MexicanFood* provide additional context about ingredients, cooking practices, and product preferences.

This mix of subreddits is useful because demand is not only influenced by prices or supply conditions, but also by what consumers are discussing, cooking, recommending, or complaining about online. In this sense, Reddit can provide qualitative signals that complement traditional numerical consumption data.

Each commodity-related post classifies as positive, neutral, or negative, allowing the model to capture changes in public perception around specific products.

The sentiment composition differs across commodities, showing that each product has its own discussion profile. For example, a commodity with a higher share of negative sentiment may reflect concerns related to price, quality, health, availability, or controversy. In contrast, a higher share of positive sentiment may be associated with recipe interest, popularity, or favourable consumer perception.

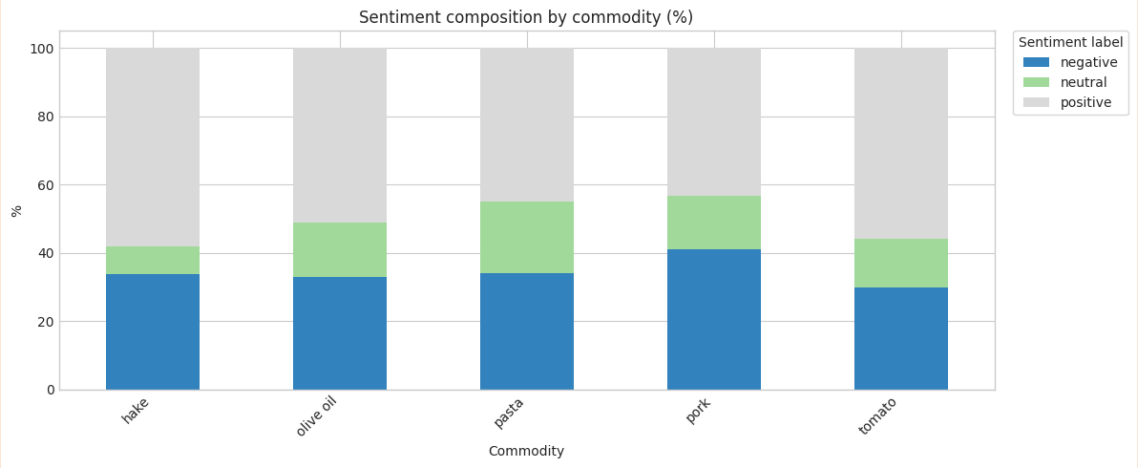

Figure 27. Sentiment composition by commodity (%)

The key idea is that online behaviour can act as an early indicator of future demand. For example, increases in searches, recipes, food-related posts, or consumer interest around a product may reveal demand changes before they appear in official consumption statistics. By incorporating these external digital signals, the model can better anticipate seasonal peals, drops, and changing consumption patterns.

This is especially relevant for commodities such as pork, where production, distribution, storage, and retail planning must often be decided months in advance. If future demand is overestimated, producers and retailers may generate surplus stock, leading to avoidable food waste. If demand is underestimated, shortages and inefficient supply allocation may occur. Therefore, more accurate demand forecasts allow the supply chain to adjust production volumes, logistics, inventories, and procurement decisions earlier.

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6 Limitations and conclusions

While this manual represents a significant step towards harmonising FL measurements, it is essential to acknowledge its inherent limitations and the broader application that shape its application.

First of all, as noted within the text, direct measurement methods like weighing were mainly tested towards crops, including potatoes, cereals, fruit and vegetables). For certain commodity products such as livestock and fisheries, direct weighing is less feasible, and one should rely on existing records and interviews, where the measurement and documentation have been carried out by third parties and the user works with pre-existing information rather than collecting the data directly.

Another remaining challenge concerns the design of sampling areas at plot level. The wide variety of food commodities, along with their specific characteristics and particularities, makes it difficult to establish clear recommendations that are both reliable and practical. In many cases, recommending sampling areas that achieve a margin of error of around 15 percent would require a level of sampling coverage that entails significant costs, potentially discouraging the measurement of losses through direct methods and leaving these stages of the chain insufficiently understood. Therefore, given the current lack of available information, obtaining field data is already considered a step forward, even if that data exceeds the 15 percent margin of error. In other words, the priority is to understand whether the magnitude of the problem is closer to 10, 100, or 1,000, rather than determining whether it is 10 or 15. For this reason, a high degree of flexibility has been adopted regarding sampling areas, based on the most relevant studies identified and referenced in the manual. In addition, it is required that results are accompanied by an analysis of the associated margin of error. Moreover, as explained throughout the manual, FL is highly dependent on the season of the year, market fluctuations and pest outbreaks, thus a single yearly measurement might not be representative of the actual losses throughout the years. Thus, the manual acknowledges the need for multi-year studies, while recognising its difficulty.

Throughout this project, and drawing on the experience of Fundació Espigoladors, gleaning activities are considered to have an additional contribution to scientific evidence, as they make it possible to determine the actual total level of losses in a given field. In this sense, both quantification methods based on sampling areas and those supported by emerging technologies can rely on these activities to validate their estimates and approximations against real conditions.

A key aspect that this manual aims to emphasise, and which is sometimes not sufficiently highlighted in FL quantification studies, is the importance of building trust with the agricultural sector, particularly when access to fields and on-site measurements is required. Engaging farmers is essential to ensure the feasibility and quality of the data collection process. It is therefore crucial to foster the involvement of the sector itself in understanding the importance of diagnosing this issue, as farmers are among those most directly affected by FL. This also reinforces the role of other stakeholders in supporting efforts to reduce them. Moreover, it is important that these analyses go beyond simply generating quantitative outputs, such as X kilograms of losses per hectare, and instead provide context to these figures. In this regard, direct dialogue with farmers is essential. For this reason, the manual highlights the need to combine an empirical approach with a perceptual one, through tools such as questionnaires and, in particular, semi-structured interviews. These methods allow space for identifying aspects that may not have been previously considered, while enabling farmers themselves to highlight what they perceive as key factors.

In conclusion, despite the challenges outlined here, it has been demonstrated that it is possible to measure FL at the pre-harvest, harvest, and post-harvest stages. Moreover, the specific case studies on different commodities offer a more precise guidance for specific sectors, recognising the high variability of each food commodity type.

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Therefore, if the aim is to assess the efficiency and sustainability of the agri-food chain in a more holistic manner, it is necessary to include these stages that precede the concept of FW. This helps to avoid unintended effects, whereby efforts to reduce FW in later stages could negatively impact the primary sector. This additional piece of the puzzle enables the prevention of such unintended consequences, improving overall efficiency across the entire chain and allowing for a better understanding of the complex interconnections between its different stages.

Finally, this manual is not an endpoint but a departure line from where building experience on FL measurements and refine the methodology towards aligned quantification methods, providing a clear pathway for a wide range of actors, including research institutions and public administrators.

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8 Annexes

8.1 Information to be gathered during direct measurement

Table 26. Recommended information to collect through perceptual approach. Text in blue denotes an example using fictitious data (Part A)

Basic data of the plot		
Name of the interviewee: Isabel García		Position of the interviewee: Owner of the farm and farmer
Farm ID	27_County_9	
Plot ID	27_County_9_A	
Location	County 9. Region X	
Crop(s)	Tomatoes	
Area/surface of the analysed parcel (ha): 3.7		
Type of soil:	Clayish	
Seed variety: Solanum lycopersicum		Cultivated variety: Roma
Plant spacing	70 cm	
Rows number: 21		Rows spacing: 1.8 metres
Method of irrigation	Drip irrigation	
Main characteristics of this year's production. Estimated production for this year.		
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.
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		

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Table 27. Recommended information to collect through perceptual approach. Text in blue denotes an example using fictitious data (Part B)

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	
Estimated harvest schedule:	
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%	
Main reasons (see reasons): C2 and B1	
Actual harvest data (to be completed once harvesting has taken place)	
Volume harvested in the plot:	• Kilos: Tonnes: 225 / 60.8 Tonnes/ha
Volume of production that has been harvested AND it has had an economic yield (marketed) for the producer?: (Economic yield = the fresh market selling price)	• Volume of marketable production (it includes fresh, 2nd class and industry), if it is paid Kilos: / Tonnes: 180 / 48.6 Tonnes/ha
	• Volume of marketable and in-fresh production Kilos: / Tonnes: 140 / 37.8 Tonnes/ha
Main reasons for the volume harvested with no economic yield for the producer:	Main reasons (see reasons): B2
Final destinations of the production harvested with no economic yield for the producer:	Animal feed

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Table 28. Recommended information to collect through perceptual approach. Text in blue denotes an example using fictitious data (Part C)

Reasons	
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	**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 organisation 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
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	
Additional aspects	
What percentage, if any, of the product produced in the plot has been donated to social entities (gleaning, food banks, charitable organisations, Red Cross, or others)?	• % from total harvest: 1% • Kilos: • Tonnes**:** 2.25
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:	

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To explain these tables, it is necessary to provide a series of clarifications.

It is important to explain the question, "*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?*" This question aims to obtain an approximate estimate from the farmer before harvesting. Therefore, if possible, it is always advisable to follow up with the farmer for confirmation of this data, as it is considered a key aspect in developing the economic sustainability assessment for each of the plots.

After the previous question, the next question appears once harvesting has taken place: "*Volume of the total production that has been harvested AND has had an economic yield (marketed) for the producer?*". Regarding the meaning, the objective is to determine the final percentage of the total harvested food that is ultimately sold (primarily fresh), thus generating an economic yield for the producer. For example, if we are quantifying an orange orchard, many of these oranges will be sold fresh, while another portion will be used for juice. This percentage would reflect the ratio of oranges sold fresh compared to the total oranges harvested.

The primary objective of this question is to understand and visualise the potential issues that may arise in certain fields, farms, and/or ponds where part of the harvested food does not reach the market as fresh produce, thus generating economic benefits for the farmer. It is true that there are alternative avenues for utilisation, even for human consumption, such as juice production; however, the price offered to the farmer for these products is often significantly lower than that of fresh produce and may not even provide any economic return at all[11]. Analysing this issue is deemed highly relevant for assessing the sustainability of the current production system and proposing solutions that address these challenges. For example, it is not sufficient to simply utilise food for human consumption or other uses if the primary avenue is not viable; the farmer should receive fair economic compensation for their work, even for these alternative uses.

[11] Fernandez-Zamudio, M.A.; Barco, H.; Schneider, F. Direct measurement of mass and economic harvest and post-harvest losses in Spanish persimmon primary production. Agric. 2020, doi:10.3390/agriculture10120581.

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Table 29 and Table 30 include the basic information that should be gathered through on-site measurement, using methods such as weighing. Certainly, this information must be anonymous and managed internally within public administrations or research centres. The aim of the table is to understand the drivers that have generated the losses measured in situ, through weighing as well as through interviews with the farmer.

Table 29. Basic form for data collection based on empirical data for each analysed parcel/plot. Text in blue denotes an example using fictitious data (Part A)

<table>
<tr><td>Date: 14/07/23</td><td colspan="2"></td><td>Author: Claudia</td></tr>
<tr><td>Farm ID</td><td colspan="3">27_County_9</td></tr>
<tr><td>Plot ID</td><td colspan="3">27_County_9_A</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="2">Crop: Tomatoes</td><td colspan="2">Type of agricultural practices (conventional, organic, or agroecological): Conventional</td></tr>
<tr><td colspan="2">Area/surface of the analysed parcel:</td><td colspan="2">• Hectares: 3.7</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Losses volumes (to be completed after measurements)</td></tr>
<tr><td>0. Volume of expected production that has been discarded/lost before reaching maturity to be harvested (optional):</td><td colspan="2">• % from expected production: 3%
• Kilos:
• Tonnes: 12</td><td>Main reasons (see reasons): A3 and A5</td></tr>
<tr><td>1. Volume of expected production that has been discarded/lost AFTER reaching maturity to be harvested and BEFORE harvesting:</td><td colspan="2">• % from expected production: 15%
• Kilos:
• Tonnes: 44</td><td>Main reasons (see reasons): A2</td></tr>
<tr><td>2. Volume of expected production that has been discarded/lost DURING harvesting:</td><td colspan="2">• % from expected production: 5%
• Kilos:
• Tonnes: 15</td><td>Main reasons (see reasons): A2 and C3</td></tr>
<tr><td>3. Volume of expected production that has been discarded/lost AFTER harvesting:</td><td colspan="2">• % from expected production: 0%
• Kilos:
• Tonnes: 0</td><td></td></tr>
<tr><td>Total food loss volumes (1+2+3)</td><td colspan="2">• % from expected production: 20%
• Kilos:
• Tonnes: 59</td><td>Main reasons (see reasons): A3, A5 and C3</td></tr>
<tr><td colspan="4">Methods of measurements:
A. Before reaching maturity to be harvested: VII
B. AFTER reaching maturity to be harvested and BEFORE harvesting: I (10% total plot) + VII
C. DURING harvesting: I (50% total plot) + VII
D. AFTER harvesting: VII</td></tr>
<tr><td colspan="4"></td></tr>
</table>

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Table 30. Basic form for data collection based on empirical data for each analysed parcel/plot. Text in blue denotes an example using fictitious data (Part B)

Reasons	
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	**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 organisation 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
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 Soil deterioration	
Methods of measurements:	
I. Direct measurement (weighing or volumetric assessment). II. Scanning/Counting III. Waste composition analysis IV. Diaries	V. Mass balance VI. Coefficients VII. Questionnaires and interviews VIII. Others

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To explain these table, it is necessary to provide a series of clarifications.

Regarding the "*Volume of total production that has been discarded/lost before reaching maturity to be harvested (optional)*" this question is considered optional because it focuses on understanding "another piece of the puzzle," separate from the concept of FL: the so-called "production losses." As indicated in the chapter "What? (1)", FL begin once the product has reached the optimal level of maturity for harvesting, slaughtering, or catching. If there is an interest in at least estimating or understanding whether the producer has any estimation or idea about the magnitude of production losses for a specific campaign, this question could be included in the interview or questionnaire prior to the fieldwork.

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Table 31. Proposed questions to include in a questionnaire to assess FL. Source: adapted from [32] (Part A)

Basic questions to the farmer
1. Use of crops on the farm
According to the crop and horticultural production survey, the farm produced the following total yield in (previous year): Instructions: Auto-filling was carried out in accordance with the crop production survey (for potatoes) or the horticultural production survey (for carrots, cabbages and strawberries). Only one crop per farm was included. **…… (name of crop) ____ kg**
Brief description of the harvesting process:
Number of cuts per agricultural campaign:
In terms of production and discards, would these cuts be of equal volume? (Yes/No): If yes: which cuts would have the highest production level and what proportion would the rest have in relation to them?
Estimated harvest calendar: Please provide the specific dates on which the harvests will take place:
How and where are harvested crops used? Instructions: If detailed data about volumes is not available, please estimate on the basis of the average volume for three previous years. This includes all activities on the farm (storage, post-harvest treatment, packaging) before any further processing. ___ % used for food, including further processing ___ % used as animal feed ___ % used for composting/bio-waste collection ___ % used for energy production ___ % other, please specify_____ *(A sum calculator to be added, together with a verifier that the total sum is 100%). Please report if the result is different from 100%.*
What are the reasons that part of the harvested crops are used for purposes other than food? Select 1-2 key reasons: (Verifier: If 100% are used for food in the previous question, this question can be ignored.) (Please select from the "reasons" section of this table). ……

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Table 32. Proposed questions to include in a questionnaire to assess FL. Source: adapted from [32] (Part B)

2. Volume of unharvested crops

Estimate the volume of unharvested crops.
Instructions: All immature produce must be discarded from this estimation. If there are no unharvested crops, enter zero.

..... (name of crop)____ kg

Why did crops remain unharvested?
Select 1–2 key reasons: *(If the previous answer was zero, this question will not be shown.)*
(Please select from the "reasons" section of this table).

.....

REASONS

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 scale/breeding scale
12) Interpersonal dynamics altering the supply chain efficiency
13) Bycatch

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 organisation
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

D. 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

Other issues not mentioned that you would like to highlight:

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Table 33. Field notebook template for recording FL direct measurements results

Quantification date					
Farmer name					
Municipality					
Quantification phase (Pre-harvest/Inter-harvest/Harvest)					
Parcel surface (m^2/ha)					
Number trees in total parcel					
Sampling (0.1, 1, 10%)					
Person in charge of quantification					
Parcel id. number	**Row id. number**	**Tree id. number**	**Edible and Marketable (g)**	**Edible but not marketable (g)**	**Neither edible nor marketable (g)**

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8.2 Selection of main drivers of food loss

Table 34. Brief description of each of the drivers that could be associated with FL, according to the main categories (Part A)

Main categories	FL Drivers	Description of the FL drivers
Behavioural	Insufficient understanding of market fluctuations and price mechanisms	Insufficient information and knowledge among primary producers concerning food market demand changes and market conditions.
	Lack of knowledge of harvest/post-harvest technologies and methods	Inadequate or limited knowledge that primary producers possess during specific production cycles, particularly concerning harvesting and post-harvesting processes and technologies.
	Lack of training	Inadequate training provided to primary producers concerning production and harvesting methods, leading to a lack of knowledge in utilising the latest technology and handling infrastructures
	Lack of investment capacity	Insufficient financial resources of primary producers to invest in key aspects of their operations (e.g., sawing, planting, harvesting).
	Inappropriate choice of product varieties (e.g., crops, breed…)	Incorrect or inappropriate choices made by primary producers when defining production lines.
	Inadequate or improper handling of the product	Lack of care adopted when handling the food product, leading to potential damage that hinders commercialisation
	Wrong collecting time (harvesting, catching…)	Food harvested and collected at an inappropriate time, potentially leading to increased food losses
	Lack of knowledge of fiscal aid tools and bureaucracy	Primary producers lack awareness or understanding of fiscal aid tools and encounter challenges related to bureaucratic processes.
	Excess of production to ensure fulfilment of contracts	Primary producers overproduce goods to guarantee the fulfilment of contractual agreements
	Lack of trust in central administration/institutions	Primary producers build lack of trust towards centralised administrations (e.g., regional, national or supranational regulatory bodies) or institutions involved in the food production and distribution system
	Inappropriate planting/breeding scale	Scale of planting or agricultural activities is not well-suited to the specific conditions, resources, or market demands
	Interpersonal dynamics altering the supply chain efficiency	Interpersonal or personal factors that disrupt the smooth functioning of the supply chain in the agricultural sector
	Bycatch	Unintentional capture of non-target or undersized marine species during fishing activities.

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Table 35. Brief description of each of the drivers that could be associated with FL, according to the main categories (Part B)

Main categories	FL Drivers	Description of the FL drivers
Societal	Low market price of food products	Challenges that farmers may face when they try to sell their products on the market. For certain products and at certain times of the year, prices for some commodities may be low. This may lead to food losses during the harvesting process.
	Low market power of farmers due to unfair contracts and competition	Unequal distribution of market power between farmers, processors, distributors and retailers.
	Marketing and industry standards (weight, aesthetic standards, size, shape, quality)	Specifications that can cover cosmetic aspects such as colour, shape and size, and are crucial in determining the ability of a product to be sold on the industrial market, or quality characteristics of the harvested products. If they don't meet these standards, crops are often left to rot in the fields or are discarded during the post-harvest selection process
	Food safety regulations and standards	Food safety, nutritional parameters, and health standards. If food commodities don't meet these standards, crops are often left to rot in the fields or are discarded during the post-harvest selection process
	Lack of coordination and communication among actors and territories	Missed opportunities stemming from inadequate cooperation and coordination among stakeholders and territories within individual supply chains and across different supply chains
	Lack of adequate supply chain capacity	Deficiency in the development of the supply chain, which can manifest as either a social or an infrastructural inadequacy
	Inefficient storage and processing infrastructure	Quantity, state of deterioration, and technological advancement of storage infrastructures including the maintenance of the cold chain.
	Inefficient transportation infrastructure	Inefficient food transportation, the of inappropriate means of transportation, and prolonged transit times to processing sites
	Direct subsidies on production	Subsidy structures designed to regulate food prices through supply management and support agricultural activities can lead to overproduction
	Market organisation	Inefficiencies arising from the market's configuration which can contribute to generate food losses.
	Marketing strategies	How producers organise themselves to enter the market and influence the pricing of agricultural products
	Lack of efficiency of equipment	Food damage due to issues related to the operation and deterioration of machinery
	Adoption of a paradigm that produce losses and waste	The way data is constructed and monitored, the priorities recognised by the actors in the supply chains, the legal lack of tools to reduce food loss, the absence of a stringent inventory policy to prioritise reducing food loss, and the low effectiveness and efficiency in the internal organisation of supply chains: all contribute to the inability to reduce food loss
	Missed application of technological advances	Lack of implementation of technological innovations
	Inability to cope with unexpected external changes	This driver involves unexpected and unaccounted-for situations, such as the Covid-19 pandemic, environmental events, changes in internal supply chain relations, etc., which can cause food loss.
	Lack of skilled labour availability	Scarcity of skilled labour in the market

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Table 36. Brief description of each of the drivers that could be associated with FL, according to the main categories (Part C)

Main categories	FL Drivers	Description of the FL drivers
Environmental	Unexpected climate and weather events	Climate changes and weather variability that can have an effect upon yield and lead to crop losses in the field
	Pests, diseases and phytosanitary issues	Pest infestations and crop diseases or leading to food losses during both the ripening and post-harvest stages, especially for fruits and vegetables
	Consumption or damage by insects, rodents, birds or microbes (e.g. Mold, bacteria), or predators	This driver highlights how agricultural production can be destroyed, damaged, or consumed by insects, rodents, birds, or microbes, both before and after harvesting
	Natural weather / meteorological conditions	Normal climatic and meteorological conditions that can lead to losses both in the different phases of plant development and in the pre-harvest and post-harvest ones, if they deviate from those optimal for the development of the plant
	Old plantations	Aging of orchards has been identified as one of the drivers contributing to food losses in primary production
	Soil deterioration	Erosion causes the loss of the most superficial and fertile part of the soil, making the land less suitable for growing crops

Within these main drivers, there may also be "sub-causes" that are encompassed within each. Table 37 identifies some of the most relevant sub-causes to consider.

Table 37. Sub-drivers to highlight within some of the identified drivers related to food loss

Main categories	Drivers	Sub-drivers
Societal	Low market price of food products	Market saturation
		End of season: low demand
		Production/harvest/post-harvest costs
		Others
	Inefficient storage and processing infrastructure	Processing industry does not exist
		Processing industry is saturated
		Does not meet quality requirements for processing
		Others
	Lack of skilled labour availability	Lack of timely help to harvest production peaks
		Personnel dedicated to other tasks
		Unable to find qualified personnel to hire
		Others

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8.3 Methodological considerations for the measurement of food loss in the food commodities tested in the case studies (T4.2)

This section sets out the main methodological considerations for the quantification of FL in the food commodities tested in the case studies (T4.2):

- Vegetables
- Fruit
- Potatoes
- Cereals
- Mussels
- Salmon
- Meat
- Milk

The purpose of this section is primarily to complement Chapter 3. HOW & WHEN? Measuring food loss at farm level.

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8.3.1 Measuring food loss in vegetables

The following section outlines the key considerations for measuring food loss in vegetables, based on the case study conducted by the Fundació Espigoladors (ESPI) in Spain.

It includes the adaptation of the food loss definitional framework to vegetables; considerations regarding the measurement methodology applied to vegetables (sampling process, direct measurement, and extrapolation of sample data); a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.1.1 Adaption of the Food Loss Definitional Framework to vegetables

The general FLDF adapts perfectly to vegetables and to their quantification.

8.3.1.2 Designing a sampling method for direct measurements collected in the plot

In vegetable crops, it is recommended to calculate the sample percentage based on the plot area.

E.g.: In a 6,400 m2 lettuce field, we sample 10% of the area, which corresponds to 640

Once the total area to be sampled has been calculated, it should be divided into subsamples distributed randomly and homogeneously across the plot, marking them with tape or some other identifying element. It is recommended to divide the total area to be sampled into 10 subsamples.

E.g.: Instead of sampling a single area of 640 m^2 (the area outlined by the dotted line in Figure 28), we divided it into 10 subsamples of 64 m^2 (the 10 numbered squares in the same figure), each representing 1% of the field. Each subsample is a quadrant of 13 m × 5 m, and they are distributed randomly across the field.

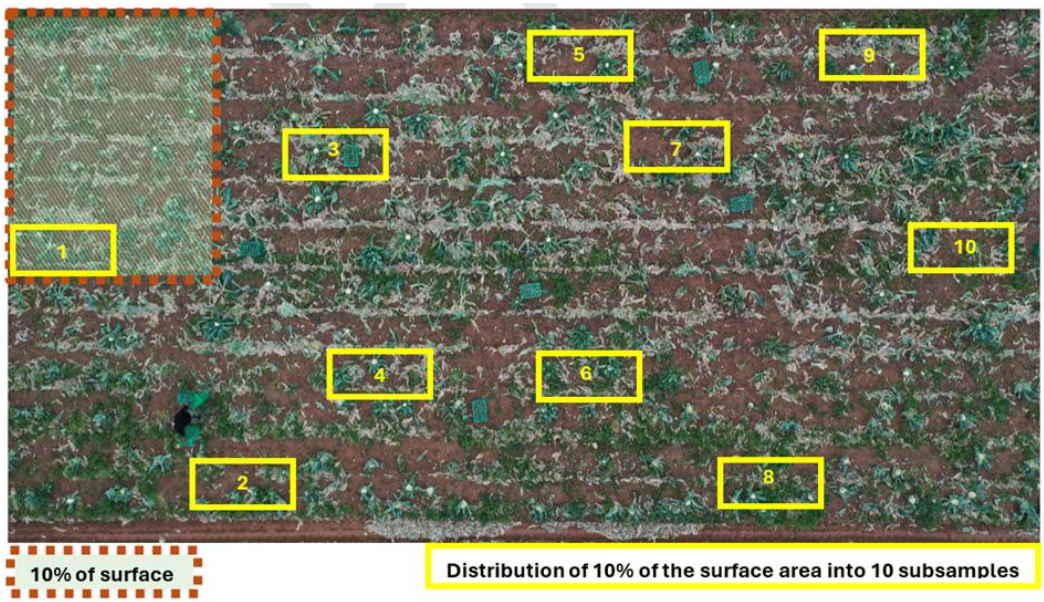

Figure 28. Field sampling method representation. Source: authors' own elaboration

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Practical recommendations for dividing the sample area into subsamples

To randomly define the location of subsamples within the plot, it is recommended to follow these steps:

Step 1. Decide on the number of subsamples to be measured, with 10 being recommended. A higher number of subsamples increases the representativeness of variability in the sampling but also requires greater effort.

Step 2. Calculate the size (area) of each subsample by dividing the sampling area, calculated in the previous section (1. Define the sample area), by the chosen number of subsamples (Step 1).

Step 3. On a sketch, divide the plot into sections of the same size as the subsamples, similar to slices of a pie, and assign a number to each section.

Step 4. Generate as many random numbers as the number of subsamples and assign the subsample locations according to the numbering defined in Step 3. The selected locations will represent the sampling points.

One issue that is also relevant, is to ask the plot owner during the interview about the best way to mark the sampling areas, or at least explain how it will be done and inquire if they have any concerns with this process. This is crucial for two reasons:

- The marking system must endure throughout the harvest, as choosing a method that gets lost during harvesting would render the measurement process impossible.
- Additionally, the marking should not interfere with the harvest, as any inconvenience caused could discourage future measurements, as the production team may view it as an obstacle to their work.

For all these reasons, it is important to maintain a degree of flexibility in marking the sampling areas so that, on one hand, it is sufficiently secure to define the area during the measurement process for harvest losses, while on the other hand, it aligns with the harvesting and crop management processes followed by the farmers. Figure 29 illustrates an example of marking the sampling areas with tape for measuring harvest losses in a conventionally grown cabbage crop.

Figure 29. Marking for harvest loss measurement in a conventional cabbage field. Source: FOLOU on-field data collection

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In any case, despite agreeing with the landowner or the workers/farmers of the crop on how to mark the sampling areas where we want to measure losses, it is advisable to **have an additional plan for identifying the sampling zones**. For example, having a drawing/image of the plot to outline the area you sampled makes it easier to revisit after the harvesting processes, ensuring that the measurement is not lost if the marked sampling areas are disturbed by weather or harvesting activities (*Figure 30*).

Figure 30. Marking of sampling areas on a map for measuring harvest losses in a conventional cabbage crop. Source: FOLOU on-field data collection

In such circumstances, a situation may arise where part of the plot has been harvested while another part remains unharvested, yet the harvest will not continue, leaving the crop abandoned. It is crucial to anticipate these situations in advance whenever possible, as in these cases, as shown in Figure 31, there are two clearly distinct areas within the plot. Therefore, employing a random sampling strategy for the entire plot would not be the most advisable approach.

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Figure 31. Measurement of food loss in conventionally produced lettuce at the end of the harvest. On the left, a portion of the unharvested (and abandoned) crop, and on the right, a portion of the same crop that has already been harvested. Source: FOLOU on-field data collection

In these cases, it is recommended to map the plot and quantify FL as if they were, initially, two separate crops. This means conducting random sampling in both areas (harvested/unharvested) and calculating their loss indices according to the area they cover. Additionally, the number of samples taken from each part of the crop should be proportional to the size of the area each occupies. This entails conducting stratified random sampling, taking into account the two clearly distinct areas (harvested/unharvested), and calculating their respective loss indices based on the proportion of the area they each occupy.

To better understand this, let's start with an example (Figure 32): imagine a lettuce field with a total area of 1.5 hectares, where two-thirds of the field has been harvested, and one-third has not been (and will not be harvested). Due to available resources, we have decided to cover a total of 1% of the field's area to assess the issue of FL. How should we proceed?

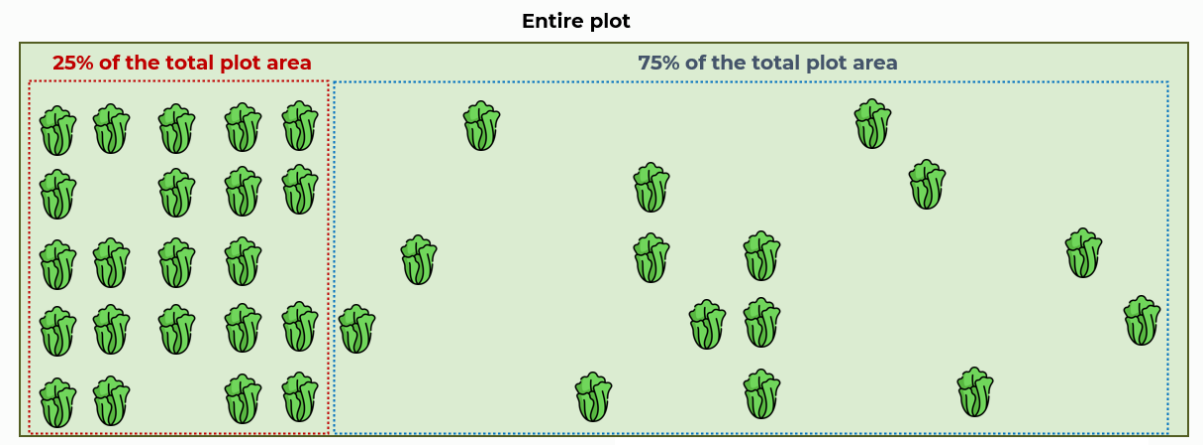

Figure 32. Example of a lettuce field where part of the plot has been harvested and another part remains unharvested and will not be harvested, where food loss measurements are to be conducted. (Lettuce icons created by Freepik – Flaticon)

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For the design of the sampling in this example, a possible solution would be as follows:

1. Divide the plot into zones based on its condition (harvested/unharvested). The field is divided into two-thirds harvested (1 ha) and one-third unharvested (0.5 ha). Since the field is clearly divided into two areas with different conditions (one harvested and one unharvested), both zones will be treated as independent subplots for sampling.

2. Calculate the sampling area for each zone. With 1% of the total area designated for sampling and given that the total field size is 1.5 hectares (or 15,000 m²), 1% of 1.5 hectares would amount to 150 m².

3. Distribute the sampling area 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:

    $150m^2$ x 66.67% = $100m^2$

    b. Unharvested zone (1/3 of the plot): This represents 33.33% of the total area, so the sampling area will be:

    $150m^2$ x 33.33%=$50m^2$

4. Select the sampling method. A stratified random sampling method will be used, where each zone (harvested and unharvested) serves as a separate stratum. Random samples will be selected within each stratum to ensure representation from both zones.

5. Sampling the plot:

    a. In the harvested zone, random sampling points will be selected, covering a total of 100 m². Given that the field follows a grid pattern (rather than row cultivation), sampling units of 10 m² can be used. Thus, 10 sampling units will be taken (10 x 10 m² = 100 m²).

    b. In the unharvested area, random sampling points will be selected to cover a total of 50 m². For example, 5 sampling units will be taken (5 x 10 m² = 50 m²).

When carrying out step number 5, a logical discussion that may arise is how many quadrants should be delineated: is it better to have 10 quadrants of 10 square meters or reduce them to 5 quadrants of 20 square meters? This decision depends on several key variables, one of the most obvious being the level of homogeneity within each differentiated stratum: the greater the heterogeneity, the higher the number of samples required. Additionally, it's important to consider the resources needed to delineate these quadrants, as more time is required to mark them off, and the greater the number of quadrants, the more time will be spent on this task. Therefore, finding the right balance between the reliability of the data collected and the practicality of the actions to be taken remains a crucial factor. As a general recommendation, it is always preferable to conduct the maximum number of quadrants possible, as this approach allows for a better capture of the crop variability across different areas of the field. However, this should be balanced with the resources required to delineate each quadrant.

The previous example is a clear illustration of how to apply a stratified random sampling method, due to the presence of two distinctly marked areas within which there was a high level of uniformity. However, in some crops, **the level of heterogeneity within a single plot can be very high**, as illustrated in *Figure 33*. In such cases, a recommended strategy is to map the entire plot according to different categories or strata that might be relatively homogeneous, for instance: areas of low, medium, and high FL density. Subsequently, similar calculations to those in the previous example would be performed.

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Figure 33. Images of the same lettuce field showing areas with highly distinct differences in food loss density. Source: FOLOU on-field data collection

This **process of delineating the sampling area** can be time-consuming if precision is required. However, there are materials that can facilitate the task, such as using soft measuring tapes, which adapt much better to the terrain's conditions, rather than rigid measuring tapes that significantly complicate the task. As shown in Figure 34, the use of rigid measuring tapes is not recommended for this task.

Figure 34. Delineation of sampling areas using a rigid measuring tape. This approach is not recommended for loss measurement. Source: FOLOU on-field data collection

8.3.1.3 Measuring losses through direct measurements in the plot

In vegetable crops it is urged to carry out the **measurement only in the harvest phase** (1-3 days after harvest). In this case, no measurement is carried out in pre-harvest.

The reason it is not done during the pre-harvest stage is that, in crops such as lettuce, cabbage, or cauliflower, taking these measurements would require cutting the plants

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before the actual harvest. At that point, it is often uncertain whether those products will ultimately become losses once the producer harvests the field. As will be discussed later, in other horticultural crops such as tomatoes or peppers, it is more feasible to carry out pre-harvest measurements (1–3 days before harvest). This allows to weigh fruits that have fallen from the plant onto the ground and have already begun to rot, making them impossible for the producer to harvest.

In addition, many producers prefer that we do not enter their fields before harvesting, as moving among the crops could potentially damage the produce.

During the harvest stage, all the produce remaining in the sampling subareas is collected, ensuring that the vegetables collected in each subsample are kept separate. As mentioned previously, only those products that have fully developed and reached a sufficient degree of maturity to be harvested or consumed will be collected and measured.

The products collected in each sampling sub-area are classified into three categories:

E.g. lettuces that remain extremely small and are unfit for consumption will not be collected or measured. On the other hand, lettuces that are large enough for consumption, even if they do not meet marketing standards, will be collected and measured.

- **Edible and marketable (EM):** those edible vegetables that, based on their size and appearance, can be marketed for fresh consumption according to market standards or other sales channels of the producer (Figure 36, C).
- **Edible, but not marketable (EnM):** these would be those vegetables that, despite being healthy and suitable for human consumption, would not have access to the fresh consumption market due to market requirements (size and appearance) (Figure 36, B).
- **Neither edible nor marketable (nEnM):** those vegetables that are rotten or affected by diseases that compromise their food safety (Figure 36, A).

Figure 35. From left to right: A) lettuces "neither edible nor edible", B) lettuces "edible, but not marketable", and C) lettuces "edible and marketable". Source: FOLOU on-field data collection

- In cases where, for logistical reasons, quantification is carried out several days after harvest, it is possible that the products may have rotted between the harvest date and the quantification date. **It is important to note that categorisation (into the three groups mentioned above) should be based on the estimated condition of the vegetables at the time of harvest**.

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In this situation, when classifying into categories, it is necessary to assess whether any incipient signs of decomposition present in some vegetables which could otherwise lead them to be classified as “non-edible” have appeared during the time between harvest and quantification. If this is the case, vegetables should be classified as edible. If the symptoms are considered advanced and the vegetable would not have been edible at the time of harvest, it should be classified as non-edible. In case of doubt, it should always be classified as non-edible.

This scenario also applies to the term “marketable.” If it is considered that esthetic deterioration occurred in the vegetable during the time between harvest and quantification, the product should be classified as edible and marketable.

Some examples of the effect of the time gap between the harvest day and the measurement day include:

- **Bolted vegetables**. If the bolted vegetables have not been harvested at the time of harvest, they should be classified in the "edible but not marketable" category. However, if it is considered that it has been bolted between the harvesting and measuring process due to an excessive time between phases, and it is considered that at the time of harvest the vegetable met the marketing requirements, the vegetable must fall into the category of "edible and marketable".

Figure 36. Bolted lettuces

- In some situations, due to an excessive time between harvesting and quantification, harvested vegetables resprout. In these cases, they should not be considered as food loss since the regrowth was not originally planned, so it is not considered part of the product intended for human consumption and therefore **should not be measured**.

Figure 37. Lettuce regrowth

- It may occur, and occasionally does, that **the measurement frames partially cover a vegetable**. In such cases, if it is a specific issue—for example, when a significant portion of a lettuce falls within the measurement frame but is not entirely covered (see Figure 38)—

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one strategy is to weigh the entire lettuce and approximately calculate the percentage covered by the frame. For instance, in Figure 38, if approximately 75% of a lettuce weighing 150 grams is covered, you would record 112.5 grams for that lettuce within the frame. This measurement should be supplemented by the weight of any additional lettuces fully contained within the frame.

Alternatively, if this situation frequently arises during sampling, to avoid excessive time consumption, you can weigh three lettuces typically sampled from the plot and calculate the average weight of a standard lettuce, for example, 150 grams. Subsequently, record the percentages of lettuces that are partially covered in the frame (e.g., 10%, 25%, 50%, 90%) and apply these percentages to the average standard weight.

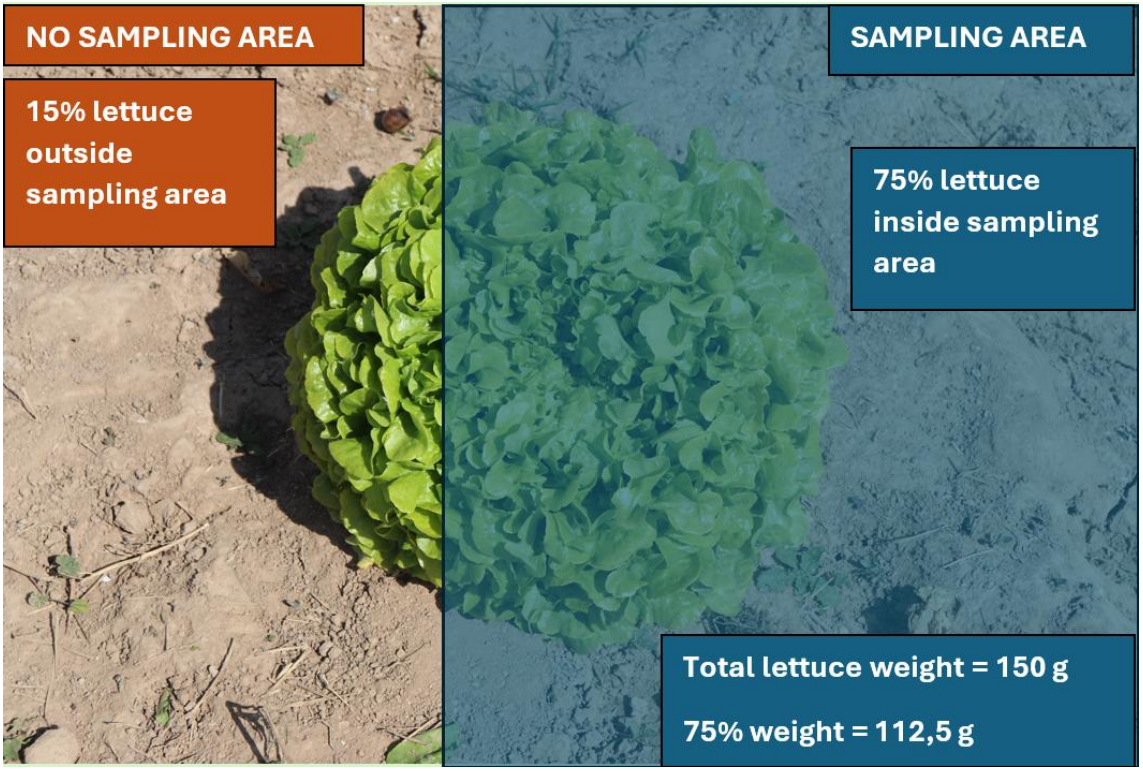

Figure 38. Lettuce partially covered by sampling area

- In relatively small fields, it is common for crops such as tomato, peppers, or similar plants to be **arranged in a few long continuous rows**. In these cases, it may be more appropriate to carry out sampling based on linear meters.

To do this, calculate the total crop length (number of rows × length of each row), and then determine the agreed sampling area, usually 10%.

E.g. if there are 5 rows of tomato plants, each 80 meters long, the total crop length is 400 linear meters. A 10% sample would correspond to 40 linear meters, which should be distributed across several sections in different rows to account for variability within the field.

- In the process of sample collection and weighing, it is crucial to emphasise that **the entire vegetable should always be measured: both the edible and non-edible parts**. To illustrate this issue, we refer to Figure 39, which shows a series of lettuces marked as edible but not marketable. When quantifying the FL for these lettuces, they should be considered as whole pieces, as depicted in the photos, without removing the outer leaves that are not edible (rotting/browned leaves) at the time of the photograph. As additional information,

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one might weigh, for example, 3 whole lettuces, calculate their average weight, remove the non-edible leaves, re-weigh them, calculate the average weight of the remaining edible parts, and determine the percentage of the lettuce that is edible at the time of sampling.

Figure 39. Image of lettuces classified as "edible but non-marketable" within the process of quantifying food loss.

- During the process of measuring FL during harvesting, there is a crucial aspect in vegetables that needs to be addressed: **how to measure losses when dealing with a product that undergoes multiple "harvests" or cuts**.

In this case, pre-harvest losses, if it is possible to measure them, could be assessed similarly to any other vegetable crop, as could post-harvest losses. The challenge lies during the harvest itself, specifically in calculating all the harvest losses. What can be done?

As discussed in Section 3.2.1, it is important to determine whether these cuts can generate similar quantities in terms of food production or not. The method for this identification is through an interview/questionnaire with the producer. Specifically, Table 27 includes three questions related to this:

- Number of cuts per agricultural campaign.
- In terms of production and discards, would these cuts be of equal volume? (Yes/No).
- Which cuts would have the highest production level and what proportion would the rest have in relation to them?

Ideally, measurements should be taken for all cuts, but this is a very complex and difficult task, particularly for crops with multiple or even continuous cuts, such as tomatoes. Therefore, measurements should be focused on very specific moments. For vegetables with multiple cuts, as a general approach, it is recommended to measure losses at the end of all cuts and, when possible, during intermediate cuts.

An example of this is illustrated in Figure 40, which depicts a tomato crop subjected to a total of five harvests. Measurements will be taken at three different stages: the first harvest, the third harvest, and the final harvest.

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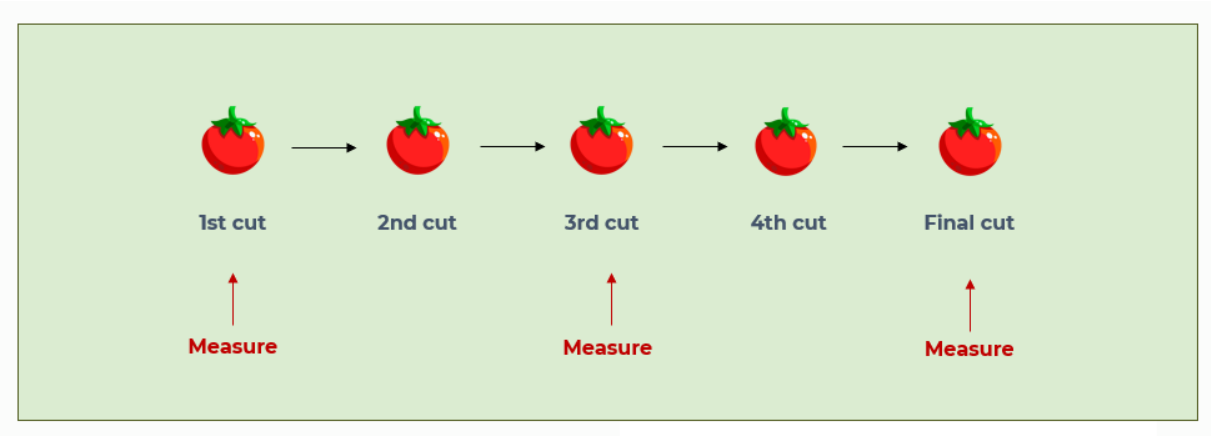

Figure 40. Example of a harvesting process, in this case a tomato crop, involving five distinct cuts. General recommendation for measuring losses where the yields between cuts are similar or data on variations is unavailable.
(Tomato icons created by justicon – Flaticon)

Using this example, if data on yields between harvests is unavailable, as illustrated in Figure 40, it is advisable to perform three measurements of FL: one at the end (which is the most recommended) and two intermediate ones. In this case, the intermediate harvests are the first and the third. Intermediate harvests are those that occur before the final harvest and prior to the removal of the crop. The proposed calculation is as follows: a loss index is established for each harvest, which will be the average of the intermediate harvests (first and third) and applied to the four intermediate harvests. These amounts will then be added to the losses calculated for the final harvest, which is considered non-extrapolable to the rest.

Continuing with this example, let us assume that the measurement of FL during the first harvest is 140 kilograms in a total plot area of 1 hectare. The third harvest results in a total loss of 85 kilograms in the same plot. The final harvest yields a loss amounting to 240 kilograms. The arithmetic means of 140 and 85 is 112.5 kilograms for each harvest, and the resulting FL figures are as depicted in Figure 41.

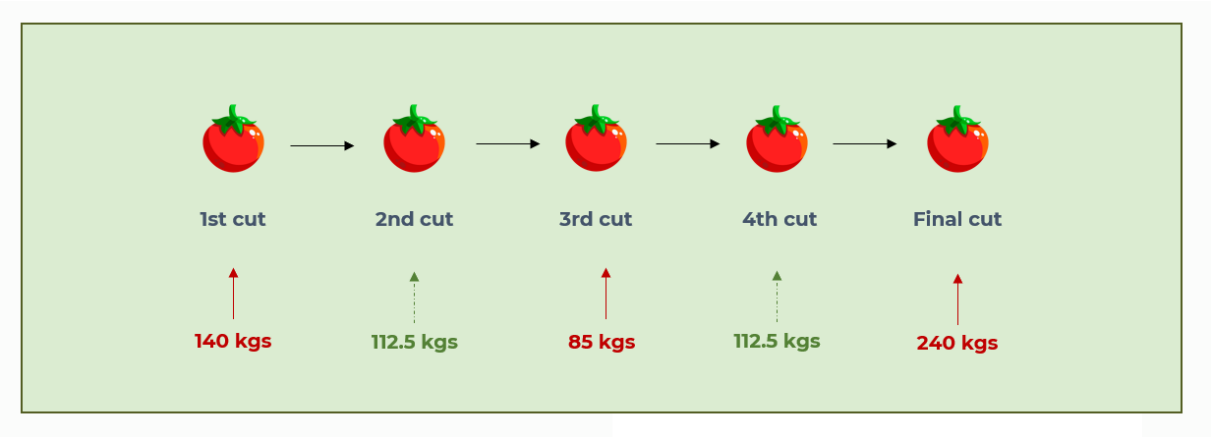

Figure 41. Example of a harvesting process, in this case a tomato crop, involving five distinct cuts. Example of information collected and estimated for the different cuts.
Note: In red, information obtained through on-site measurement. In green, estimated data.
(Tomato icons created by justicon – Flaticon)

In this way, the calculation of total losses for all the cuts in this one-hectare plot would be 140 + (112.5 x 2) + 85 + 240 = 690 kilograms. Since this amount pertains to a one-hectare plot, it would therefore result in an index of 690 kilograms per hectare.

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Although we already have the figures for FL per hectare, these values will also be reflected considering the total crop yield. In this way, the creation of an index (FL Index) is proposed, which will follow the formula:

$$FL\ Index = \frac{FL}{Total\ harvested + FL} x\ 100$$

FL represents the amount of food loss (in tons or kilograms), and "Total harvested" refers to the total quantity of the crop harvested during an entire season for a specific commodity.

In the case of multi-harvest crops, the total harvest will logically be the sum of all the cuts throughout the agricultural season. To clarify this point, let's refer back to the previous example: imagine that in addition to having the data on harvest losses, we also have the figures for the yields from these cuts, but due to certain circumstances, we do not have the final harvest data:

- 1st cut = 2.3 tons.
- 3rd cut = 1.8 tons.
- Final cut = 4.7 tons.

Since both the total yield and the yields from cuts 2 and 4 are unknown, estimates similar to those used for calculating FL will be made: these cuts will be assumed to be the average of the yields from cuts 1 and 3.

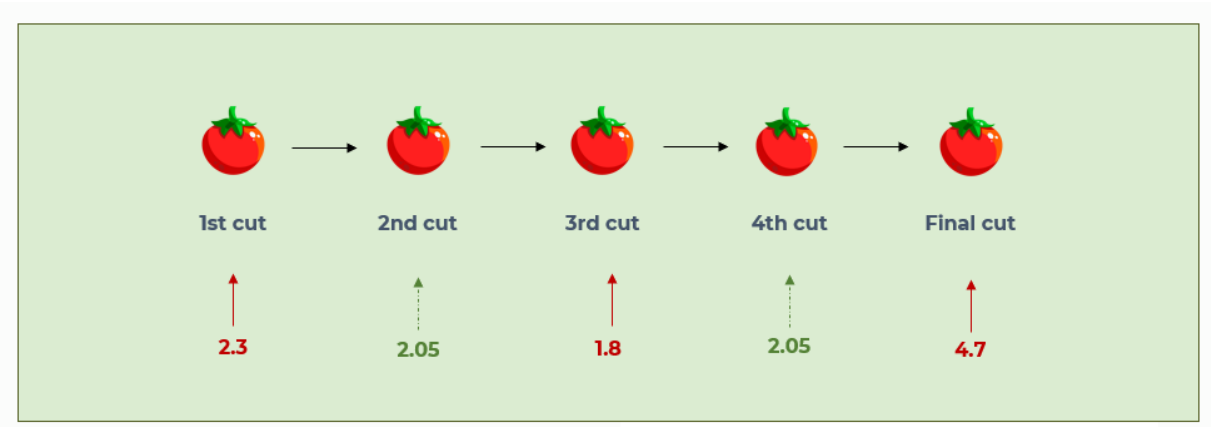

Figure 42. Example of a harvesting process, in this case a tomato crop, involving five distinct cuts. Example of yields collected for specific cuts, in tonnes.
Note: In red, information obtained through on-site measurement. In green, estimated data.
(Tomato icons created by justicon – Flaticon)

Taking these results into account, the final harvest would be as follows: 2.3 + (2.05 x 2) + 1.8 + 4.7 =12.9 tons of tomatoes (total harvested).

As previously mentioned, harvest losses have been calculated here, but it would be necessary to add, if possible or available, the pre-harvest and post-harvest losses in order to account for the total food loss of tomatoes during that season.

Within this example, it should be noted that, for instance, the pre-harvest losses amounted to 25 kilograms and the post-harvest losses were 2 kilograms. Therefore, the general framework of this example would be summarised in Figure 43. Thus, it can be concluded that the total food loss for this tomato crop during that season amount to 25 + 690 + 2 = 717 kilograms = 0.72 tons.

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Figure 43. Example of measuring total food loss in a tomato crop, according to key stages.

With the data on total losses and total harvest, the proposed formula for calculating the FL index put forward by FOLOU can be applied:

$$FL\ Index = \frac{FL}{Total\ harvested + FL}\ x\ 100$$

$$FL\ Index = \frac{0.72}{12.9 + 0.72}\ x\ 100 = 5.28$$

This means that, of the total losses (pre-harvest, harvest, and post-harvest) combined with the harvest, 5.28% represents losses, while 94.7% constitutes harvested food.

An alternative, if measuring the cuts individually is not possible and only the final cut can be quantified (Figure 44), is to reference the level of losses concerning the percentage of total production that each cut is estimated to generate. In other words, the farmer should provide an approximate estimate of the quantity produced in each cut, or the percentage that each cut contributes in relation to the most productive cut.

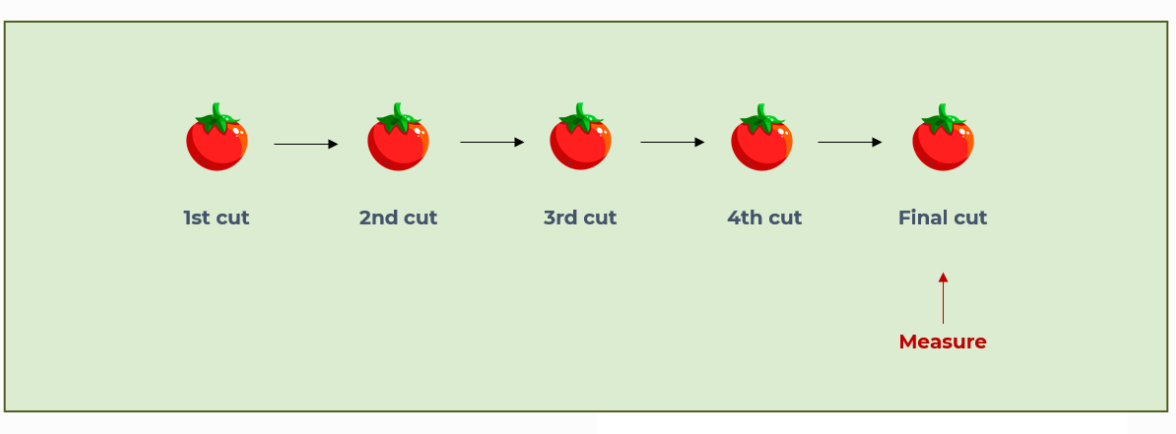

Figure 44. Example of a harvesting process, in this case a tomato crop, involving five distinct cuts. General recommendation for measuring losses when only the final cut can be measured.
(Tomato icons created by justicon – Flaticon)

In the table concerning the questionnaire/interview that should be conducted with the farmer (Table 27), there are three questions regarding this matter:

- Number of cuts per agricultural campaign:
- In terms of production and discards, would these cuts be of equal volume? (Yes/No):
- Which cuts would have the highest production level, and what proportion would the rest have in relation to them?

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Let's assume the farmer indicates that:

- The number of cuts is 5.
- The production volumes of these cuts are not similar.
- The cut with the highest production level is the final cut. The previous cuts have a percentage in relation to the next final cut as follows: 1st cut = 60% (of the total production of the final cut); 2nd cut = 20%; 3rd cut = 35%; 4th cut = 30%.

If, in this case, we have conducted a final measurement that results in a total of 1,000 kilograms of losses, and the final cut produced 25,000 kilograms, this would yield a FL rate of 3.84%. Thus, we can apply these calculations to the other cuts (Figure 45):

- 1st cut: 25,000 (60%) = 15,000 kilograms of production. Assuming a similar FL level as calculated: 3.84%.

$$FL\ Index\ (harvesting\ phase) = \frac{FL}{Total\ harvested + FL}\ x\ 100$$

$$3.84 = \frac{FL}{15{,}000 + FL}\ x\ 100$$

$$FL = \frac{57{,}600}{96.16} = 600$$

Another way to obtain the same result is by calculating the proportion of losses based on the final harvest:

$$\frac{FL}{Total\ harvested}\ x\ 100$$

In this case, by applying the example data once again, it would be as follows:

$$\frac{1{,}000}{25{,}000}\ x\ 100 = 4$$

In this case, the interpretation of the index differs from the FL Index. The FL Index indicates what percentage of the total, including both generated losses and the final harvest, corresponds to losses and what portion is associated with the harvested yield. Here, the calculation refers to the equivalence of losses in relation to the total harvested. In other words, "X kilos/tonnes of losses were generated in this plot, which is equivalent to Y% of the total harvest obtained". Hence, there are two different percentages: the calculated 4% indicates that the number of measured losses is equivalent to 4% of the total harvest obtained.

In this case, for the calculation of losses for cut 1, we apply the 4% to the production for this cut (25,000):

15,000 (4%) = 600 kilos of FL.

By applying one of these two methodologies to the remaining cuts, the following results would be obtained:

- 2nd cut: 25,000 (20%) = 5,000 kilograms of production. 5,000 (4%) = 200 kilograms of losses.

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- 3rd cut: 25,000 (35%) = 8,750 kilograms of production. 8,750 (4%) = 350 kilograms of losses.
- 4th cut: 25,000 (30%) = 7,500 kilograms of production. 7,500 (4%) = 300 kilograms of losses.

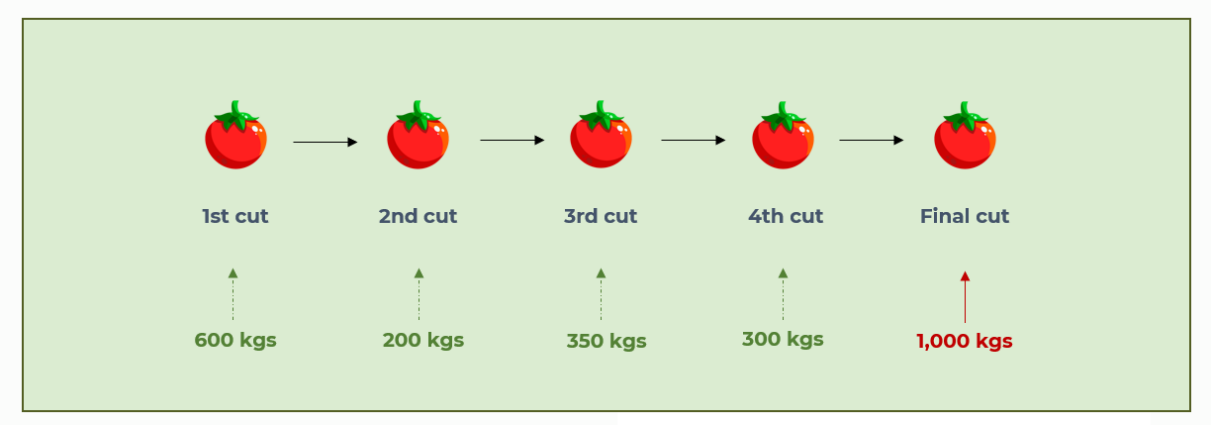

Figure 45. Example of a harvesting process, in this case a tomato crop, involving five distinct cuts. Example for measuring losses when only the final cut can be measured.
Note: In red, information obtained through on-site measurement. In green, estimated data.
(Tomato icons created by justicon – Flaticon)

By summing all calculated and/or quantified losses: 1,000 + 600 + 200 + 350 + 300 = 2,450 kilograms of losses. When referred to one hectare, this would result in an index of 2,450 kilograms per hectare or 2.4 tons per hectare.

To calculate the FL Index for the total production, the same steps as in the first example should be followed, and including pre-harvest and post-harvest losses, if applicable.

One final possibility that could arise is conducting a loss measurement in a specific plot (e.g., 2nd cut, as shown in Figure 46), knowing the total production (from all plots), but without knowing the production of each individual plot, including the one where the loss measurement was taken. In this case, although it is obviously less reliable than the previous options, it is suggested that the farmer himself estimate, approximately, the percentage of the total production contributed by each plot for that year.

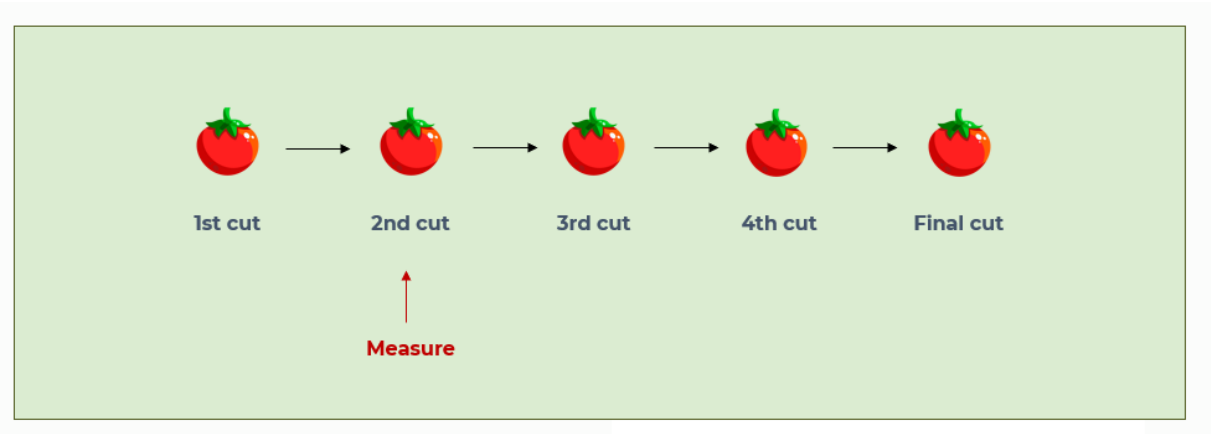

Figure 46. Example of a harvesting process, in this case a tomato crop, involving five distinct cuts. Example for measuring losses when production data by cut is unknown.
(Tomato icons created by justicon – Flaticon)

Let's imagine that the total production for a growing season (all cuts combined) is 60,000 kilos of tomatoes, a figure that is known with certainty. Additionally, in-situ measurements indicate that for the 2nd cut, there were a total of 800 kilos of losses. Furthermore, based on

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an interview with the farmer, we know the approximate contribution of each cut to the total production as follows: 1st cut (15% of total production), 2nd cut (10%), 3rd cut (25%), 4th cut (5%), and final cut (45%). With this information, the calculations would be as follows:

If the total production is 60,000 kilos and the contribution from the 2nd cut is 10%, this would imply an estimated production of 6,000 kilos for this cut. Given that the quantified losses are 800 kilos. As in the previous case, calculating the FL rate for this cut:

$$FL\ Index\ (cut) = \frac{FL}{Total\ harvested + FL}\ x\ 100$$

$$FL\ Index = \frac{800}{6{,}000 + 800}\ x\ 100 = 11.8$$

Since we have no other reference points, we will assume that these FL Indexes are similar for each cut. Therefore, the total losses for the season would be:

$$11.8 = \frac{FL}{60{,}000 + FL}\ x\ 100$$

$$FL\ Index\ (harvesting\ phase) = \frac{FL}{60{,}000 + FL}\ x\ 100 = \frac{708{,}000}{88{,}2} = 8{,}027\ kilos\ of\ Total\ FL$$

If we want to break down these losses by cut, we simply apply the percentages the farmer estimated for each cut:

- 1st cut: 8,027 (15%) = 1,204.
- 2nd cut = 800.
- 3rd cut: 8,027 (25%) = 2,006.
- 4th cut: 8,027 (5%) = 401.
- 5th cut: 8,027 (45%) = 3,612.

Figure 47 summarises these calculations. While the most relevant figure may be the total losses (7,980 kilos), it is also possible to make estimates to understand the potential levels of losses occurring across the different cuts in each season.

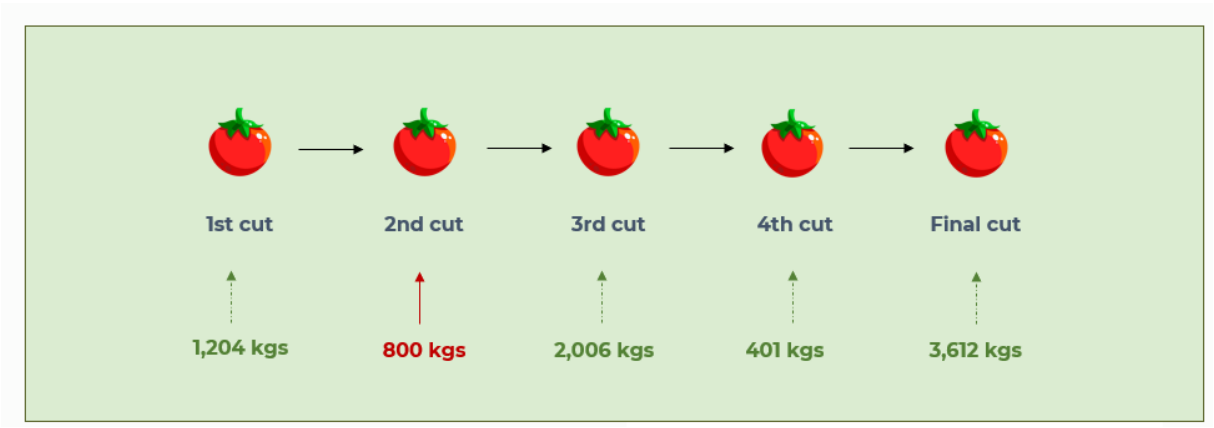

Figure 47. Example of a harvesting process, in this case a tomato crop, involving five distinct cuts. Example for measuring losses when production data by cut is unknown.
Note: In red, information obtained through on-site measurement. In green, estimated data.
(Tomato icons created by justicon – Flaticon)

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However, it is important to note in these examples that the loss figures provided by cut refer to one hectare, which is precisely the size of the plot. This has been done to simplify the calculations. If this is not the case, the following section will detail how results are extrapolated, both for the plot and for an entire territory (3.4.5).

Just like in the other two examples, to calculate the FL Index for the total production, the same steps as in the first example should be followed, starting from Figure 33, and incorporating pre-harvest and post-harvest losses, if applicable.

- On some occasions, in this type of multi-harvest crops, it may happen that during the food collection process in each cut, throwing inedible/unmarketable on the floor, which are losses mentioned earlier in terms of how to calculate them, there are also instances where **food is collected in cuts where sorting occurs very close to the plot** (e.g. 100 meters). This is due to a sorting process in which some of these foods are stored in boxes for what are referred to as **category C** foods, which are offered to the public in case they are purchased in the following days (e.g. 5-6 days), and if not, they too will be lost (e.g.
- Figure 48). Therefore, it is important to identify these flows generated within the plot or the agricultural parcel, as they should be added to the losses calculated previously. This would be a clear example of post-harvest losses, which should be added to the harvest losses calculated using some of the proposed options, along with the pre-harvest losses, if they exist or have been measured.

Figure 48. Image of tomatoes collected in a cut and stored as category C.

- For **post-harvest losses**, as explained in the chapter related to the "WHAT," these involve very specific and particular issues. Therefore, conducting on-site measurement processes of this magnitude may not be necessary in most cases. Such measurements should only be considered when specific instances of food loss are identified, particularly those managed as waste (not sent to animal feed or classified as by-products). To identify these instances, Table 27 includes the question: "Final destination of the production harvested with no economic yield for the producer," which can help determine whether measuring is necessary. In the example shown in Table 27, if the discard is destined for animal feed, these discards are not considered food loss and would fall outside the scope of the analysis. However, if the discards are sent for incineration, it would be classified as either FW or FL, depending on whether the managing entity has waste disposal licenses. Given the sensitivity of this information, it will be up to the measurement team to seek additional information to distinguish between FW and FL. If it is not possible to make this distinction, the flow will be classified as FW/FL. Information collection at this stage can be achieved through various sources: records from the farm itself, direct measurements, or information

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gathered by the farmer through interviews/questionnaires. As a general rule for vegetables, the final destination of post-harvest discards within the farm/plot should be queried in the questionnaires/interviews, along with their magnitude.

8.3.1.4 Extrapolation of sample data

The extrapolation of the sampling data to the entire plot follows the steps indicated in the general manual.

For each of the data categories (EM, EnM, nEnM, TOTAL), calculate the following parameters:

- Maximum value
- Minimum value
- Median
- Average
- Standard deviation

The median value of each category will be considered as representative to extrapolate the data to the entire plot and calculate the FL index.

Food loss (FL) in the total plot	$FL\ plot\ =\ Median\ \cdot \frac{100\%}{x\%}$
Food loss index	$FL\ index = \frac{FL\ plot}{Plot\ production + FL\ plot} \cdot 100$
	x% represents the size of the subsample

To extrapolate FL data from crops with more than one harvest, refer to the example described in the previous section.

Practical recommendations for extrapolation of data to the total parcel

To determine the plot production, there are two possible approaches:

A) The ideal method is to ask the farmer directly for the average production per season; that is, how many kilograms they usually harvest from that plot per sowing.

B) If this information is not available, production can be estimated using regional yield statistics published by public authorities. For example, the most recent statistics for Catalonia can be consulted here.

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8.3.1.5 *Illustrative measurements. Vegetable case study in Spain.*

A 6,400 m² lettuce field was quantified. For this purpose, 10% of the total area (640 m²) was sampled. This area was divided into 10 subsamples of 64 m² (8 m × 8 m), randomly distributed across the field, as the plot was considered homogeneous in terms of losses. Table 38 shows the FL data in each sample.

Table 38. Food loss data of each sample

Sample identification (n°)	Edible and marketable (g)	Edible but not marketable (g)	Neither edible nor marketable (g)	Total (g)
1	0	6,620	1,280	7,900
2	0	5,510	0	5,510
3	0	7,410	1,300	8,710
4	0	4,580	0	4,580
5	0	4,740	5,90	5,330
5	0	4,960	2,200	7,160
11	0	1,980	3,960	5,940
8	0	2,100	2,90	2,390
4	0	2,270	1,570	3,840
2	0	2,870	2,450	5,320

The mean, median, standard deviation, and maximum and minimum values of the samples were calculated to examine the data Table 39.

Table 39. Parameters calculated from the FL data.

Category	Maximum value (g)	Minimum value (g)	Mean (g)	Median (g)	Standard deviation (g)
Edible and marketable	0	0	0	0	0
Edible but not marketable	7,410	1,980	4,304	4,660	1,933
Neither edible and marketable	3,960	0	1,364	1,290	1,254
Total	8,710	2,390	5,668	5,420	1,888

The data were extrapolated to the entire plot using the median values (Table 40). To perform the extrapolation, the median values of each category were multiplied by 100, since in this case each subsample represented 1% of the field

Table 40. Data extrapolated tot the entire plot

Category	LOSSES PER PLOT (kg)	LOSSES PER HA (kg/ha)
Edible and marketable	0	0
Edible but not marketable	466	728.125
Neither edible nor marketable	129	201.5625
Total	542	846.875

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To calculate the FL index, the total production of the field was consulted, and the following formula was applied:

$$FL\ index = \frac{FL\ plot}{Plot\ production + FL\ plot} \cdot 100 = \frac{542}{11{,}498 + 542} \cdot 100 = 4{,}5\ \%$$

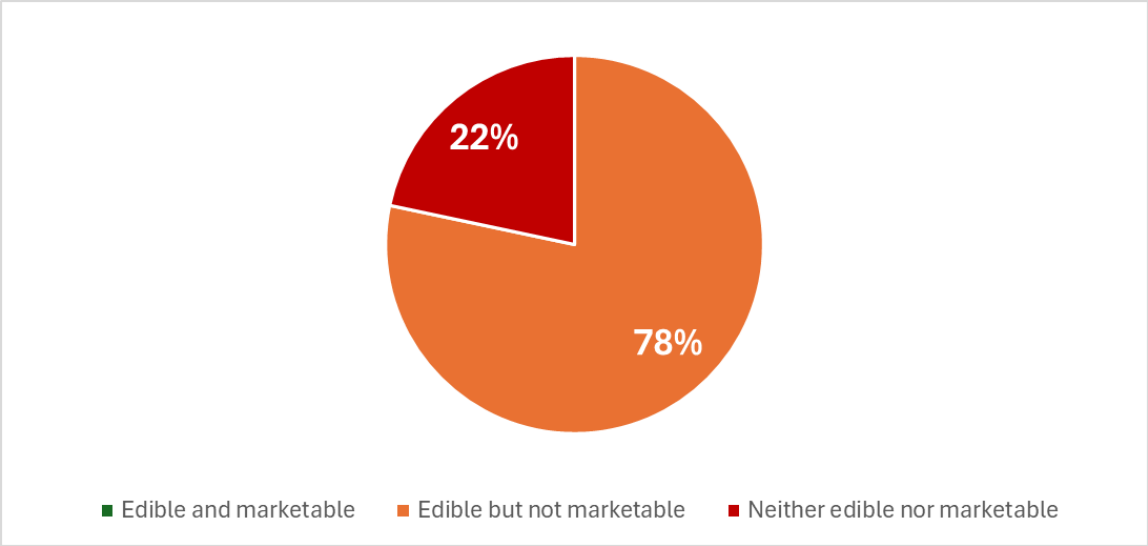

Figure 49. Distribution of food loss categories

8.3.1.6 Measuring costs

According to the experience developed by Espigoladors in conducting on-field measurements, the time and human resources required for sampling are the following: for a field of about 700 m2, sampling its 10%, two people and about 1- 1,5 hour would be necessary to sort and weigh the sample by the three driver's categories. Subsequently, 30 minutes would be necessary to input the collected data into a software (e.g. Excel), process the data and extrapolate them for the entire field and the region.

8.3.1.7 Adaptation to other food commodities

This measurement methodology is perfectly suited to the crops with which it has been tested: lettuce, cabbage, cauliflower, and tomato. In addition, it is estimated that it can be easily adapted to other similar crops that grow above ground, such as peppers, eggplant, beans, chard, spinach, broccoli, artichoke, pumpkin, watermelon, melon, and cucumber, etc.

For underground vegetables such as tubers, roots, and bulbs, refer to the considerations in the potato case study (Annex 8.3.4).

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8.3.2 Measuring food loss in fruit trees

®WWF/ Santi Donaire

The following section outlines the key considerations for measuring food loss in fruit trees, based on the case study conducted by the Fundació Espigoladors (ESPI) in Spain.

It includes the adaptation of the food loss definitional framework to fruits; considerations regarding the measurement methodology applied to fruits (sampling process, direct measurement, and extrapolation of sample data); a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.2.1 Adaption of the Food Loss Definitional Framework to vegetables

The general FLDF adapts perfectly to vegetables and to their quantification.

8.3.2.2 Designing a sampling method for direct measurements collected in the plot

For fruit trees, it is recommended to calculate the sample as a percentage of the total number of trees in the plot.

E.g.: In a plot of mandarin trees with 40 trees, we sample 10%, which corresponds to 4 trees.

Practical recommendations for defining the sample area for fruit trees:

Step 1. To calculate the number of trees in the plot, when planting rows are regular, it is recommended to count the number of trees in a single row and multiply this by the total number of rows in the plot.
(Example: in the case of Figure 2, we multiply the 4 trees of each row by the 10 rows: 4 x 10=40)

Through satellite imagery, using tools such as Google Maps or Google Earth, it is sometimes possible to count and distinguish tree canopies, making the counting process more accessible.

Step 2. To calculate the area of the plot, it is recommended to use apps that allow easy measurement via satellite imagery, such as Google Maps or Google Earth.

Once the **number of trees** to be sampled has been calculated, they must **be distributed randomly and homogeneously in the parcel**, marking them with tape or some identifying element. In this case, each tree to be sampled is considered a subsample.

E.g. We distribute the 4 trees to be sampled randomly throughout the plot (Figure 50).

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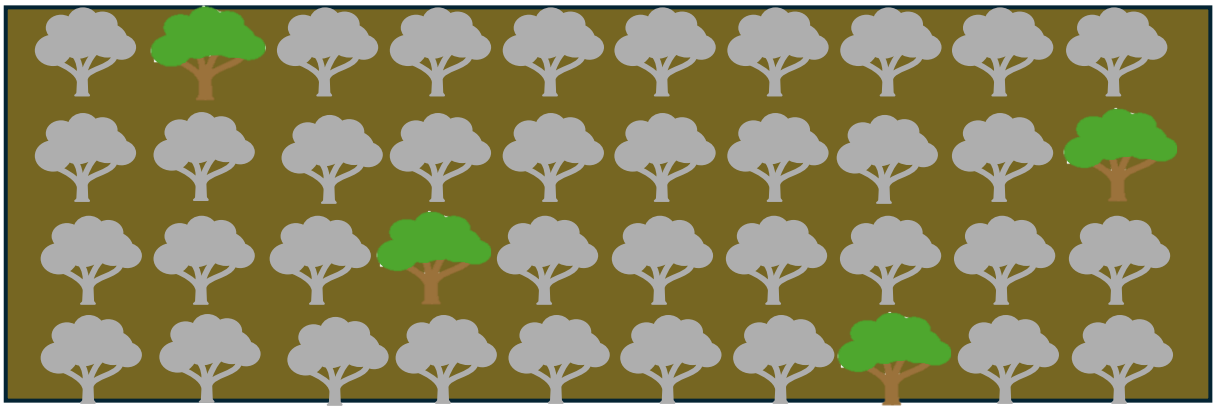

Figure 50. Representation of sampling in a field of fruit trees. Source: authors' own elaboration

Practical recommendations for dividing the sample area into subsamples

To randomly select the trees to be measured, it is recommended to follow these steps:

Step 1. On a sketch, assign a number to each tree in the plot. It is useful to assign numbers to the trees within each row, starting with 1 for the tree closest to a reference point and increasing sequentially for trees further away.

Step 2. Generate as many random numbers as the number of trees to be measured, calculated in the previous section (1. Define the sampling area) and assign the tree locations according to the numbering defined in Step 1. The selected trees will represent the sampling points.

It is recommended to tag each tree that will be quantified (e.g. Figure 52). The tagging should be visible but difficult to remove, as it needs to remain in place for both the pre-harvest stage and the subsequent harvest process. In any case, some loss of tags is expected, so it is essential to create sketches/maps identifying these trees as a complement, either on paper or digitally.

Figure 51. Tagging sampled fruit-trees. Source: FOLOU on-field data collection

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8.3.2.3 *Measuring losses through direct measurements in the plot*

In fruit tree crops it is urged to carry out the **measurement both in the pre-harvest** (1-3 days before harvest) **and harvest phase** (1-3 days after harvest).

- **Pre-harvest stage:** collect the fruit that has fallen to the ground beneath the canopy of the sampled trees or around its zone of influence (defined in Figure 53). In this stage, only fallen fruit is collected, while the fruit remaining on the tree is left intact for the upcoming harvest.
- **Harvest stage:** both the fruit that has fallen to the ground and the fruit that has remained on the trees after the harvest of the trees in the sampling are collected.

Figure 52. A) Area of influence defined by tree. (Apple-tree icons created by wanicon – Flaticon). B) In the case of a slope, the area of influence of the trees of one row or another is defined by drawing a line in the middle between the two rows. ® (WWF/Santi Donaire).

Regarding the zone of influence, some errors should be considered, such as fruit movements due to slopes or displacements for other reasons, although they are usually very small volumes or even non-existent in some cases. However, there are cases where the slopes may be very steep, and in such instances, the tree's area of influence must be adjusted accordingly.

According to the proposed definition of FL, only fruits that have fully developed and reached a sufficient degree of maturity for harvesting or consumption should be collected and measured, as otherwise they represent production losses.

E.g.: Pears that are extremely small (see Figure 53), and that have not yet developed internally, will not be collected or measured. On the other hand, those pears that have been developed internally and are of sufficient size for consumption, despite not complying with marketing requirements, will be collected and measured.

Figure 53. Immature pears identified during the loss measurement process. Source: FOLOU on-field data collection

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The products collected in each sample tree are classified into three categories:

- **Edible and marketable (EM):** those edible fruits that, due to their size and appearance, can be marketed for fresh consumption following the requirements of the market or other marketing channels of the producer (Figure 55, C).
- **Edible, but not marketable (EnM):** these are fruits that, although healthy and suitable for human consumption, would not reach the fresh market due to market requirements regarding size and appearance (Figure 55, B).
- **Neither edible nor marketable (nEnM):** those fruits that are rotten or affected by diseases that compromise their food safety (Figure 55, A).

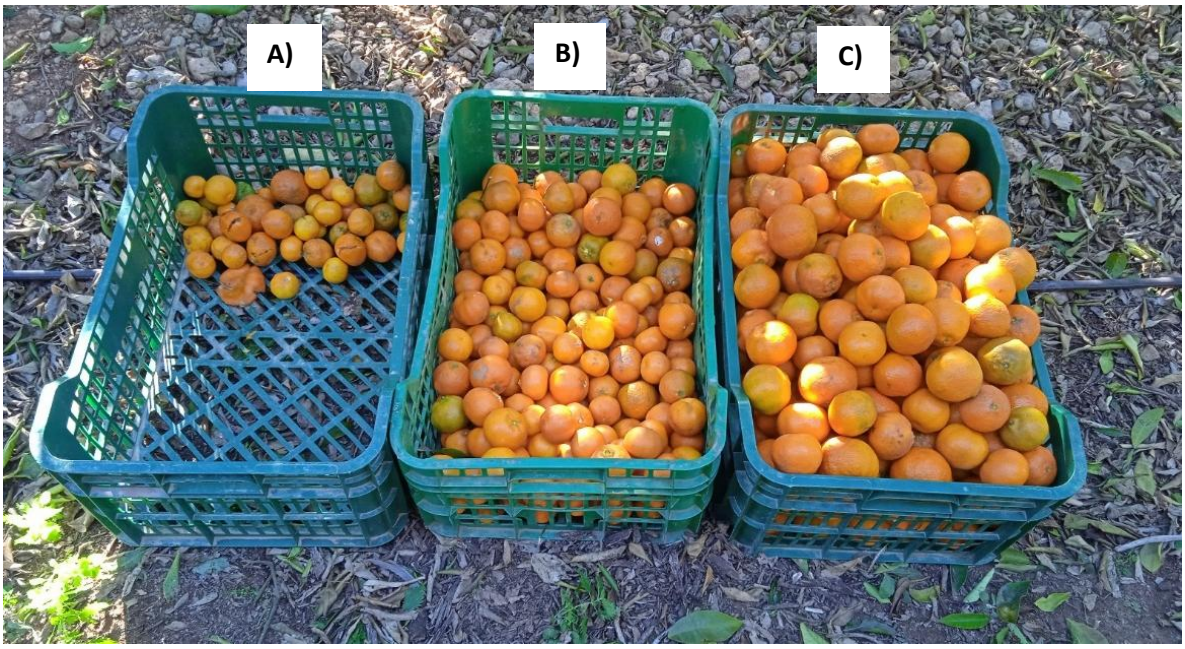

Figure 54. From left to right: A) mandarins "neither edible nor marketable", B) mandarins "edible but not marketable", and C) mandarins "edible and marketable". Source: FOLOU on-field data collection

Those fruits collected and weighed at pre-harvest stage must subsequently be removed from sampling areas to avoid double counting when measuring losses during the harvest of the same trees.

There may be certain cases that raise doubts, and this manual aims to provide guidelines to facilitate the standardisation of processes and comparability between studies:

- **The effect of the time between harvesting and quantification**

In cases where, due to logistical issues, quantification is carried out several days after harvest, it is possible that the products have deteriorated between the date of harvest and the date of quantification. It is important to note that classification into categories must be based on the estimated condition of the fruits at the time of harvest.

In this situation, when classifying fruits, it should be assessed whether any incipient sign of decomposition, which would otherwise classify the fruit as "inedible," appeared during the period between harvest and quantification. If this is the case, the fruits should be classified as "edible." An example would be fruit that was left on the tree after harvest and was edible, but between the harvest and quantification fell on the ground, where a damp spot and mould has started to appear on the side of the fruit in contact with the soil.

If the symptoms are advanced, and the fruit would not have been considered edible at the time of harvest, it should be classified as "inedible." When in doubt, fruits should always be classified as "inedible."

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This same principle applies to the term "marketable." If the fruit has suffered aesthetic deterioration during the period between harvest and quantification, it should still be classified as "edible and marketable.

- **How should we measure if we have a crop with multiple harvest phases?**

Ideally, it is necessary to measure the losses in the soil in the pre-harvest phase and at the end of each of the harvests, and in the case of the last stage, also measure what remains in the unharvested tree.

To quantify in intermediate harvests (those that are before the final harvest), only the product that has fallen to the ground is collected and measured. At the end of the measurement in each of the intermediate phases, the fruits that had been weighed must be removed from the sampling areas, to prevent them from being measured again by mistake in subsequent quantifications, which would lead to an overestimation of the losses. Only in the last harvest should both what is on the ground and what has not been harvested on the tree be collected and measured.

If it is not possible to carry out the measurement in each of the harvest phases, carry out the measurement in the last and in the maximum number of intermediate phases.

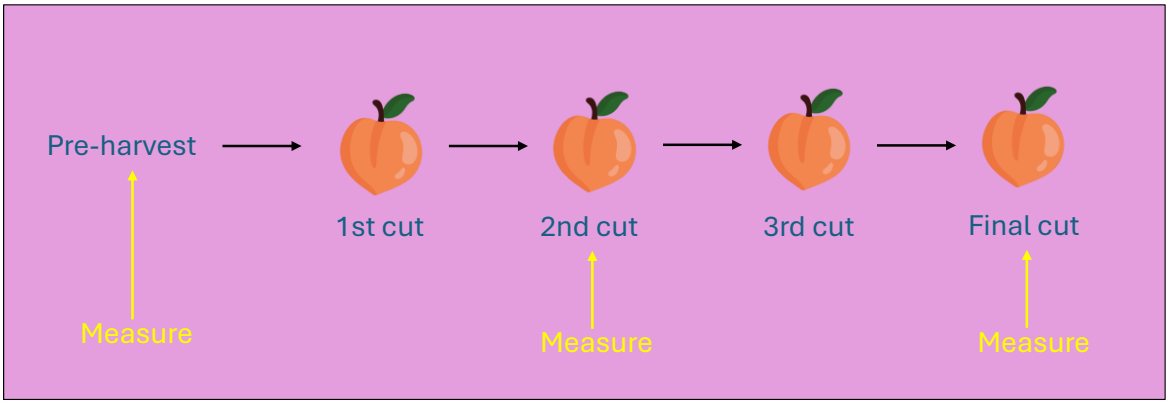

Figure 55. Measurement stages in crops with multiple harvest phases

- **Is it necessary to weigh the entire piece, including its edible and inedible parts?**

Yes. The whole piece must be weighed, including the edible parts as well as the inedible parts (e.g. the skin of the fruit, its seeds, bone, or peduncle).

Figure 56. Pears with peduncle

- **How should fruits with mechanical damage on the surface be categorised?**

As a rule, if the damage to the skin of the fruit is superficial and does not affect its interior, the fruit would be classified as "edible". However, if the inner part has been affected or is exposed to the environment due to the wound, the fruit should be classified as "inedible".

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- **How should you categorise the fruits that are on the ground removed by thinning?**

Thinning is carried out during fruit growth, where excess and smaller fruits are removed from the trees in order to promote the growth and quality of the rest. As those fruits that are still in the growth stage, and therefore are still immature, are removed, it should not be considered as FL.

- **Are the discarded products from fruit trees planted exclusively to promote pollination considered food loss?**

Since the discarded fruits come from trees planted exclusively to promote pollination, and therefore were not planted with the intention of human consumption, these discards fall outside the scope of the FL concept and should not be collected for measurement. However, this does not mean they should be wasted; within the framework of a circular economy and food use efficiency, strategies should be sought to prevent them from being left unused in the field.

8.3.2.4 Extrapolation of sample data

The extrapolation of the sampling data to the entire plot follows the steps indicated in the general manual.

For each of the data categories (EM, EnM, nEnM, TOTAL), calculate the following parameters:

- Maximum value
- Minimum value
- Median
- Average
- Standard deviation

The median value of each category will be considered as representative to extrapolate the data to the entire plot and calculate the FL index.

Food loss (FL) in the total plot	$FL\ plot\ =\ Median\ \cdot \frac{100\%}{x\%}$
Food loss index	$FL\ index = \frac{FL\ plot}{Plot\ production + FL\ plot} \cdot 100$
	x% represents the size of the subsample

Practical recommendations for extrapolation of data to the total parcel

To determine the plot production, there are two possible approaches:

A) The ideal method is to ask the farmer directly for the average production per season; that is, how many kilograms they usually harvest from that plot per campaign.

B) If this information is not available, production can be estimated using regional yield statistics published by public authorities. For example, the most recent statistics for Catalonia can be consulted here.

To extrapolate FL data from crops with more than one harvest, refer to the example described in the vegetable annex (8.3.1).

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8.3.2.5 *Illustrative measurements. Vegetable case study in Spain.*

A 0.4 ha mandarin field with 100 trees has been quantified, and a 10% sample of the trees (10 trees) has been measured. The trees to be sampled were assigned randomly. In the pre-harvest stage, only losses on the ground were measured. In the harvest phase, both the product discarded on the ground and that remaining in the tree canopy during harvesting were measured (Table 41).

Table 41. Pre-harvest and harvest food loss data of each sample. EM=Edible and marketable; EnM=Edible but not marketable; nEnM=Neither edible nor marketable.

SAMPLE ID	PRE-HARVEST LOSSES				HARVEST LOSSES			
	EM (g)	EnM (g)	nEnM (g)	Total	EM (g)	EnM (g)	nEnM (g)	Total
1	0	80	180	260	770	760	1,120	2,650
2	0	170	270	440	570	4,570	980	6,120
3	180	200	330	710	940	1,380	470	2,790
4	0	0	160	160	1,040	1490	530	3,060
5	0	0	110	110	440	640	200	1,280
6	90	70	0	160	380	930	340	1,650
7	0	0	290	290	1,310	2,400	830	4,540
8	0	140	490	630	1,640	3,300	410	5,350
9	370	60	90	520	270	5,490	100	5,860
10	0	0	550	550	180	530	180	890

To calculate the total losses for each sample, the measurements from both the pre-harvest and harvest stages for each tree must be summed (Table 42).

Table 42. Total food loss for each sample. EM=Edible and marketable; EnM=Edible but not marketable; nEnM=Neither edible nor marketable.

SAMPLE ID	PRE-HARVEST + HARVEST FOOD LOSS			
	EM (g)	EnM (g)	nEnM (g)	Total
1	770	840	1,300	2,910
2	570	4,740	1,250	6,560
3	1,120	1,580	800	3,500
4	1,040	1,490	690	3,220
5	440	640	310	1,390
6	470	1,000	340	1,810
7	1,310	2,400	1,120	4,830
8	1,640	3,440	900	5,980
9	640	5,550	190	6,380
10	180	530	730	1,440

The mean, median, standard deviation, and maximum and minimum values of the samples were calculated to examine the data.

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Table 43. Parameters calculated from the FL data.

Category	Maximum value (g)	Minimum value (g)	Mean (g)	Median (g)	Standard deviation (g)
Edible and marketable	1,640	180	818	705	450
Edible but not marketable	5,550	530	2,221	1,535	1,784
Neither edible and marketable	1,300	190	763	765	393
Total	6,560	1,390	3,802	3,360	2,018

The data were extrapolated to the entire plot using the median values (Table 44). To perform the extrapolation, the median values of each category were multiplied by 100, since in this case each subsample (a single tree) represented 1% of the field.

Table 44. Data extrapolated tot the entire plot

Category	LOSSES PER PLOT (kg)	LOSSES PER HA (kg/ha)
Edible and marketable	71	176
Edible but not marketable	154	384
Neither edible nor marketable	77	191
Total	336	840

To calculate the FL index, the total production of the field was consulted, and the following formula was applied:

$$FL\ index = \frac{FL\ plot}{Plot\ production + FL\ plot} \cdot 100 = \frac{336}{8{,}000 + 336} \cdot 100 = 9{,}5\ \%$$

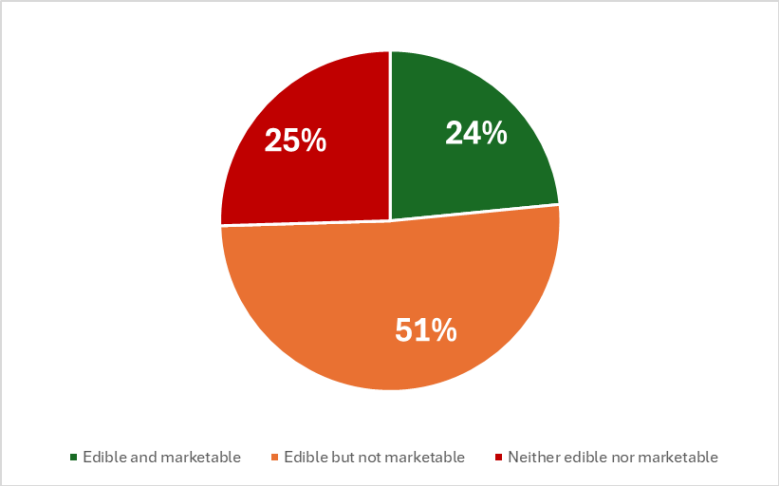

Figure 57. Distribution of food loss categories

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8.3.2.6 *Measuring costs*

According to the experience developed by Espigoladors in conducting on-field measurements, the time and human resources required for sampling are the following: for a field of about 460 fruit trees (6.255 m^2), sampling its 10%, three people and about 2 hour would be necessary to sort and weigh the sample by the three drivers' categories. Subsequently, 30 minutes would be necessary to input the collected data into a software (e.g. Excel), process the data and extrapolate them for the entire field and the region.

8.3.2.7 *Adaptation to other food commodities*

This measurement methodology is perfectly suited to the crops with which it has been tested: apple, pear, peaches/nectarines, orange, tangerine, and plum. In addition, it is estimated that it can be easily adapted to other similar crops, such as cherry, fig, or apricot, among other.

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8.3.3 Measuring food loss in cereals

The following section outlines the key considerations for measuring food loss in cereals, with a particular focus on wheat (Triticum turgidum subsp. durum) and maize (Zea mays), based on the case study conducted by the Università Politecnica delle Marche (UNIVPM) in Italy.

It includes the adaptation of the food loss definitional framework to cereals; considerations regarding the measurement methodology applied to cereals (sampling process, direct measurement, and extrapolation of sample data); a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.3.1 Adaptation of the food loss definitional framework to cereals

The general FLDF adapts perfectly to cereals, particularly wheat and maize, and to their quantification.

8.3.3.2 Designing a sampling method for direct measurements collected in the plot

The approach is based on the FAO's methodology for measuring cereal losses[12], which recommends using 1 or 2 frames of around 10m x 5m or 5m x 5m, although these frames could be smaller if there is a high crop density (e.g., wheat).

Since wheat has a highly variable plant density per square meter, but generally among the densest of crops (i.e., 400-600 plants per m^2), this manual proposes reducing the size of the sampling frames suggested by the FAO methodology, for both wheat and maize. Specifically, it is recommended that the size of the frames be 1 m^2 (1 m × 1 m), in order to avoid impractically long measurement times. Indeed, the density and size of cereal fields make it necessary to reduce the sampling size to below 1% of the field. However, it is required that the sampled area be at least equivalent to 0.1% of the field's surface area. In this regard, as many 1 m^2 sample frames as required should be established to achieve the selected sample size (at least 0.1% of the field). These frames must then be randomly distributed across the field in order to capture field variability. Nevertheless, it is possible to increase the sampling unit size beyond 1 m^2 in order to reduce the total number of quadrats and make sampling operationally more efficient. The final choice of unit area should balance representativeness, spatial resolution, and field effort, and be adjusted to the scale of the variable of interest.

Due to the large size of cereal fields, it is recommended to use GPS-based georeferencing to identify the sampling frames measured.

[12] 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.

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8.3.3.3 *Measuring losses through direct measurements in the plot*

In wheat and maize crops, **the measurement is urged to be carried out only during the harvest phase** (1–10 days after harvest). This timing is possible because cereals are less perishable than fruits or vegetables, for which measurements are generally recommended to be conducted no later than three days after harvest.

In the case of cereals, carrying out measurements during the pre-harvest stage is not recommended due to logistical issues observed in the case study. The density of the crops makes manual measurement during the pre-harvest stage very difficult. In addition, based on UNIVPM's experience in their case study, losses at this stage have been found to be almost negligible.

For both wheat and maize, counting kernels/grains on the ground within designated samples after the harvesting machinery passed through allows for the estimation of harvest losses.

Figure 59 shows the process of measuring pre-harvest food loss carried out by UNIVPM. As shown in the figure, particularly in the case of wheat (a), grain counting becomes difficult due to the high crop density; therefore, it is not recommended to carry out the measurement during the pre-harvest stage. Figure 59 a and c show the 1 m × 1 m sampling quadrats that should be measured during the harvest phase.

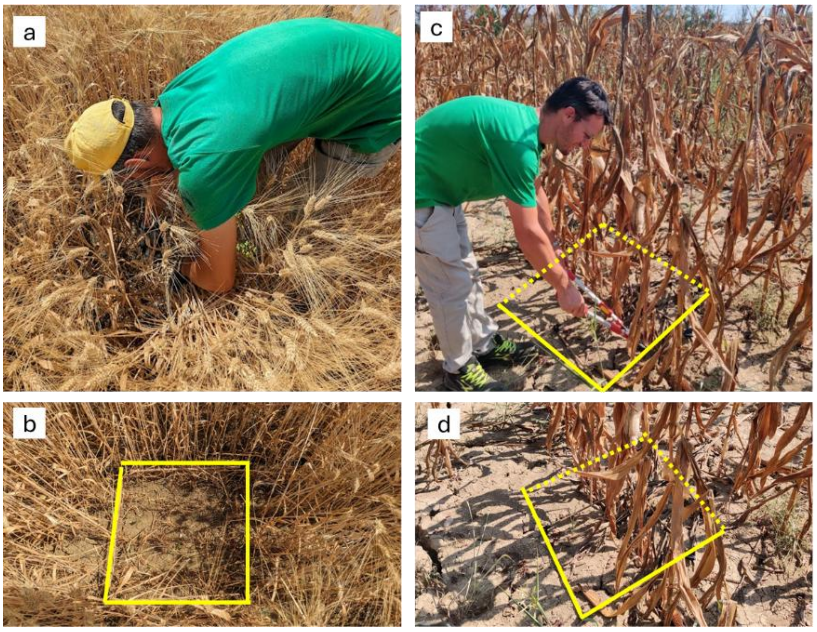

Figure 58. Field assessment of grain losses and sampling setup. (a) Counting wheat grains on the soil surface; (b) placement of the sampling quadrat for wheat; (c) counting maize grains on the soil; (d) placement of the sampling quadrat for maize. Source: FOLOU on-field data collection

Based on the experience from the cereal case study carried out by UNIVPM, it is considered unnecessary to categorise grains remaining in the field after harvest as *edible marketable*, *edible but not marketable*, or *not edible*. The main reason is that the principal driver of harvest losses is related to inefficiencies of the harvesting machinery, rather than to whether the cereal is marketable or not. In practice, whenever the product is edible, it is almost always harvested and enters commercial channels, partly because cereals have a long post-harvest shelf life and can be stored for several months.

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Although cereals are generally harvested regardless of their quality category, the protein content of the grains is a key factor determining the price received by farmers. **Mon et al. 2016**[13] argue that when the protein content of durum wheat falls below 14.3%, the price paid at the farm level decreases significantly. For cereals, the main issue is not that food remains unharvested in the field, but rather that production must be supported by optimal agronomic management, with outcomes inevitably conditioned by weather variability (e.g., rainfall patterns and distribution in the case of rainfed wheat), in order to ensure sufficiently high protein content and avoid economic disadvantages for farmers.

Even in cases where cereal crops show a high incidence of disease, fields are usually harvested to avoid the persistence and spread of inoculum, which could increase risks for subsequent crops. Moreover, fields are typically part of crop rotations, and harvesting therefore represents a necessary step in the production cycle. In situations of severe disease driven by adverse weather conditions, the crop may instead be downgraded (for example, from human consumption to animal feed), resulting in significant economic losses for the farmer rather than abandonment of the harvest.

8.3.3.4 Extrapolation of sample data

To convert grain numbers into mass, the measured 100 grain weight for each replicate is used. Individual grain weight is calculated as:

$$1\ grain\ weight\ =\ 100\ grain\ weight\ (g)\ /\ 100$$

To estimate the total food loss (FL) weight in each sample (FL_{sample} (g/m²)), multiply the weight of an individual grain by the total number of grains collected in each sampling area.

$$FL_{sample}(g/m^2) = 1\ grain\ weight\ (g) \cdot n\ grains_{sample}$$

The median food loss of the samples (g/m²) is considered as the reference value to extrapolate losses to the entire field:

$$Harvest\ FL\ \left(\frac{t}{ha}\right) =\ Median\ FL_{sample}\ \left(\frac{g}{m^2}\right) \cdot \frac{Field\ size\ (m^2)}{Field\ size\ (ha)} \cdot \frac{1\ t}{10^6\ g}$$

Finally, food loss can be expressed as a percentage of the field's production using two parameters:

$$FL\ (\%) = \frac{Harvest\ FL\ (\frac{t}{ha})}{Yield\ \left(\frac{t}{ha}\right)} \times 100$$

$$FL\ index\ (\%) = \frac{Harvest\ FL\ (\frac{t}{ha})}{Yield\ \left(\frac{t}{ha}\right) + Harvest\ FL\ (\frac{t}{ha})} \times 100$$

Based on the experience from the case study, losses occurring at the stages covered by the current concept of food loss are considered relatively limited in the case of both wheat and maize when compared to earlier stages during the growing period. These earlier stages,

[13] Mon, J., Bronson, K. F., Hunsaker, D. J., Thorp, K. R., White, J. W., & French, A. N. (2016). Interactive effects of nitrogen fertilization and irrigation on grain yield, canopy temperature, and nitrogen use efficiency in overhead sprinkler-irrigated durum wheat. *Field Crops Research*, *191*. https://doi.org/10.1016/j.fcr.2016.02.011

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which fall under the concept of production losses, account for substantial losses and merit further attention and continued research.

In this context, the Italian case study proposes a new methodology to jointly measure production losses and food loss based on field yield. For more information, see Deliverable 4.2 of the FOLOU project.

8.3.3.5 Illustrative measurements. Wheat case study in Italy.

In the measurement of FL in harvest, two to five grains per square meter were recorded, which equates to about 48,000 grains per hectare under conventional management and around 12,000 grains per hectare under agroecological management, while no grains were found in the organic fields. Although these figures may appear large, the losses are negligible as shown in Figure 59.

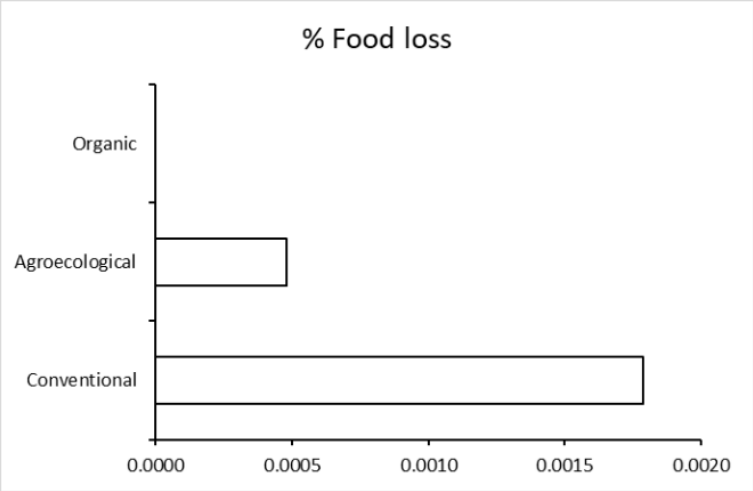

Figure 59. Wheat grain yield loss (%) in the three management systems

8.3.3.6 Measuring costs

Based on the Italian case study, food loss measurements in harvest stage generally take about one hour per field (plus travel time by car) and involve 2–3 people.

8.3.3.7 Adaptation to other food commodities

The proposed methodology applied in this study can be readily adapted to other cereal crops such as barley, rye, oats, or sorghum. With appropriate adjustments, it may also be extended to legumes and oilseeds.

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8.3.4 Measuring food loss in potatoes

The following section outlines the key considerations for measuring food loss in potatoes, based on the case study conducted by the Universiteit Gent (UGENT) in Belgium.

It includes the adaptation of the food loss definitional framework to potatoes; considerations regarding the measurement methodology applied to potatoes (sampling process, direct measurement, and extrapolation of sample data); a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.4.1 Adaptation of the food loss definitional framework to potatoes

The general FLDF adapts perfectly to potatoes and to their quantification.

8.3.4.2 Designing a sampling method for direct measurements collected in the plot

The field sampling strategy for the case study was based on the approach used by Schneider et al. (2019)[14], where randomly located 10 m linear sections were used, but adapted here to 1 m² frames (1 m × 1 m).

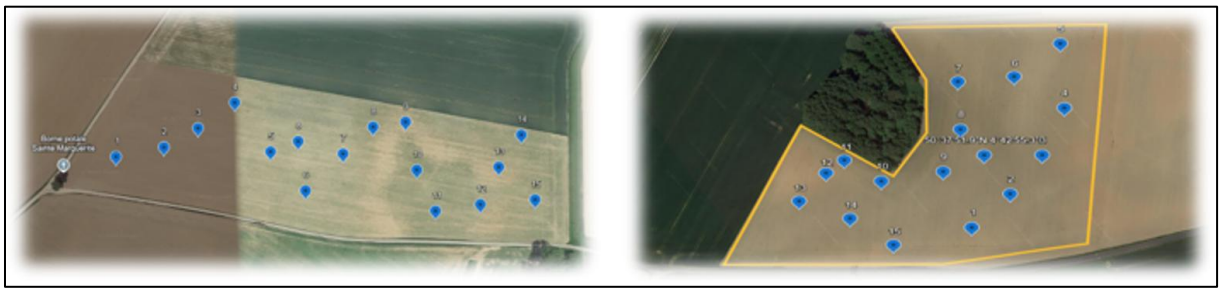

Figure 60. Images of two plots quantifying food loss in potatoes

Subsequent experiments have indicated that increasing both the number of frames and the size of each frame improves the precision of food loss estimates. In this case, the optimal configuration was found to be seven sampling units of 6 m² each (covering the 0,4% of a 6ha plot), in order to achieve a precision of approximately 15% at a 95% confidence interval. For further information, please refer to Deliverable D4.2, which will be published at the end of June.

[14] Schneider, F.; Part, F.; Göbel, C.; Langen, N.; Gerhards, C.; Kraus, G.F.; Ritter, G. A methodological approach for the on-site quantification of food losses in primary production: Austrian and German case studies using the example of potato harvest. Waste Manag. 2019, doi:10.1016/j.wasman.2019.01.020

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8.3.4.3 *Measuring losses through direct measurements in the plot*

In potato crops it is urged to carry out the **measurement only in the harvest phase** (1-3 days after harvest). In this case, no measurement is carried out in pre-harvest, as it would involve excavating the soil prior to harvest and interfering with the farmer's production.

To quantify during the harvest phase, the soil in the designated sampling areas is excavated, the potatoes discarded during harvest are collected, classified into the designated categories and weighed.

- **Edible and marketable**: those edible potatoes that, based on their size and appearance, can be marketed for fresh consumption according to market standards or other sales channels of the producer.
- **Edible but not marketable:** Those vegetables that, despite being healthy and suitable for human consumption, would not have access to the fresh consumption market due to market requirements (size and appearance), such as potatoes that are undersized or oversized.
- **Neither edible nor marketable:** those potatoes that are rotten, affected by diseases, or damaged during harvest, that compromise their food safety.

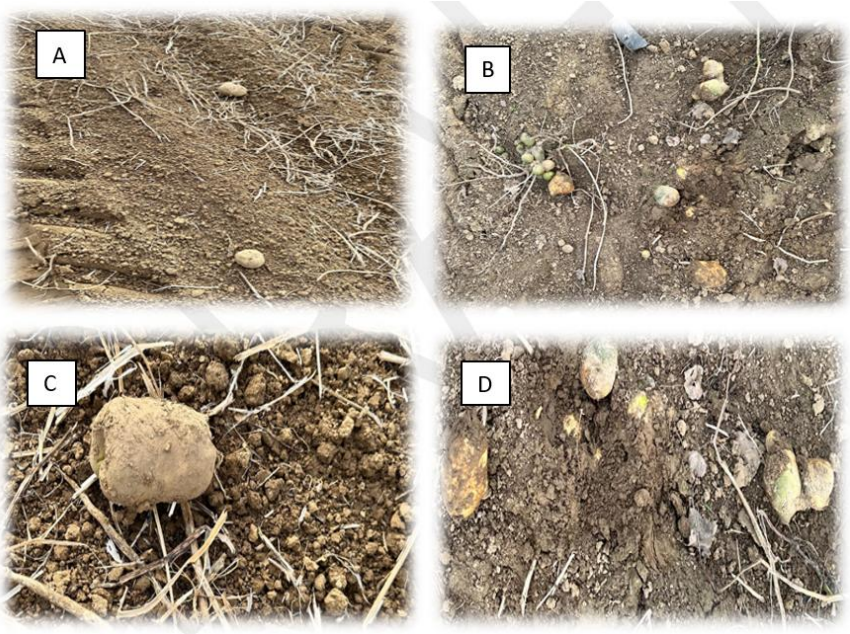

Figure 61. A: Undersized potatoes <35mm; B: Marketable size potatoes but Unharvested; C: Oversized potatoes >50mm; D: Damaged potatoes. Source: FOLOU on-field data collection

8.3.4.4 *Extrapolation of sample data*

The data analysis and the extrapolation of losses to the entire potato field follow the same guidelines as those generally indicated in the manual.

8.3.4.5 *Illustrative measurements. Potato case study in Belgium.*

The Allegria variety in Walhain yielded a total of 364.46 tons (58.78 t/ha), with food loss of 14.7 tons (2.3 t/ha), which is 4.5% of the total harvest. Most of the losses were in the "oversized tuber" category (>50 mm), which includes tubers that were not collected or were damaged during harvesting. This is because Allegria naturally produces larger tubers that are more

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likely to break down when they are harvested. On the other hand, small tubers (less than 35 mm) and medium-sized tubers (35–50 mm) didn't add much to the total losses.

For the Jelly variety, the total production was 305.23 tons (52.7 t/ha), and the food loss were 8.36 tons (1.4 t/ha), which is 2.7% of the total yield. The main reason Jelly was unsuccessful turned out because it had too small tubers (less than 35 mm) that didn't grow adequately to be marketed. This outcome is associated with factors such as nutrient limitations, planting density, or other cultivation issues. Figure 1 below summarises the total losses for Allegria and Jelly.

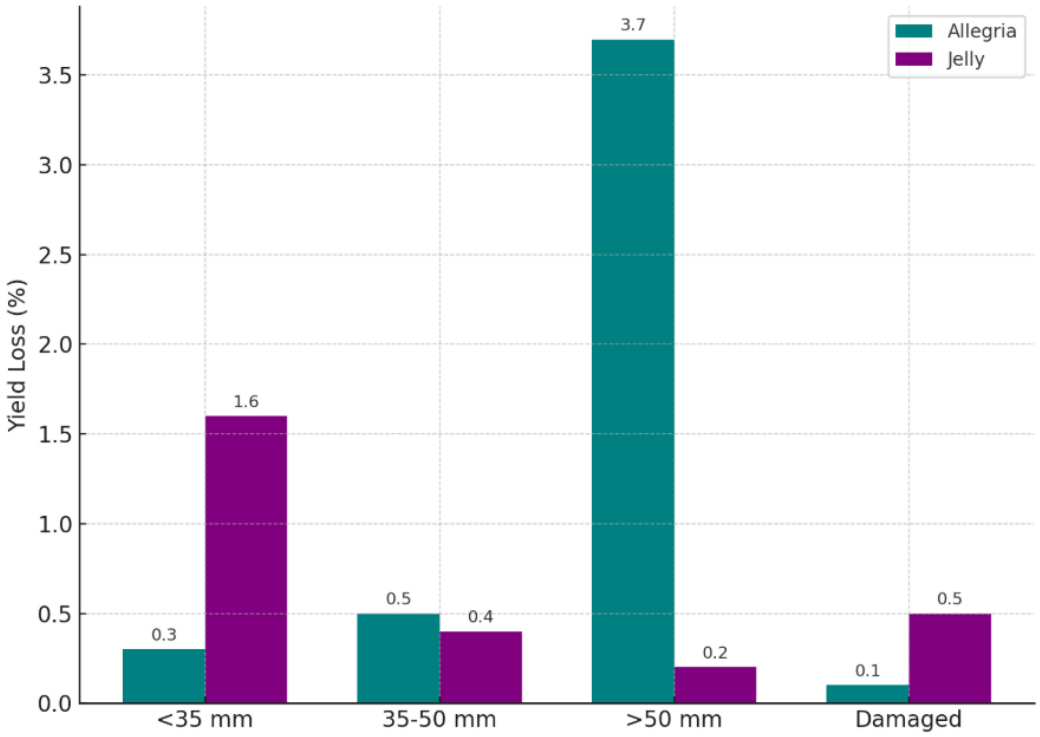

Figure 62. Total food loss of Allegria and Jelly potato varieties. 2024.

8.3.4.6 Measuring costs

According to experience from the case study carried out by Ghent University, quantifying a 6 ha field during the harvest phase took one full day and required the involvement of two to three people. The main limiting factor in the quantification process is the excavation stage. This step is particularly labour-intensive, as recovering all tubers from the soil requires careful manual digging to avoid missing smaller or deeper potatoes.

8.3.4.7 Adaptation to other food commodities

Many other crops that are harvested in a similar manner, such as bulb crops (onions, garlic) and root and tuber crops (carrots, beets, cassava, sweet potatoes), where size and harvest efficiency play a significant role in determining food loss, can readily adopt the methodological approach presented above.

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8.3.5 Measuring food loss in mussels

The following section outlines the key considerations for measuring food loss in mussels (*Mytilus galloprovincialis)*, based on the case study conducted by the Università Politecnica delle Marche (UNIVPM).

It includes the adaptation of the food loss definitional framework to mussels; considerations regarding the measurement methodology applied to mussels (sampling process, direct measurement, and extrapolation of sample data); a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.5.1 Adaptation of the food loss definitional framework to mussels

The general FLDF fits perfectly with the case of mussels. It only needed to be adapted to some specific characteristics of mussel trade, as shown in Figure 64, which identifies three main pathways:

1. A more standard pathway, in which mussels are harvested at commercial size for local distribution, around 5 centimetres in major length, and sold on the market.
2. A second pathway in which mussels are harvested before reaching the standard commercial size, at around 3.5 centimetres in major length, for national transport to other locations within the country. Within this second pathway, two possibilities may occur:
    - 2.1 Upon arrival at the destination, the mussels are sold directly on the market at the 3.5-centimeter size.
    - 2.2 Upon arrival, the mussels are returned to the sea to continue growing in different marine environmental conditions (thus modifying organoleptic features), until they reach the standard commercial size of 5 centimetres in major length for subsequent sale.

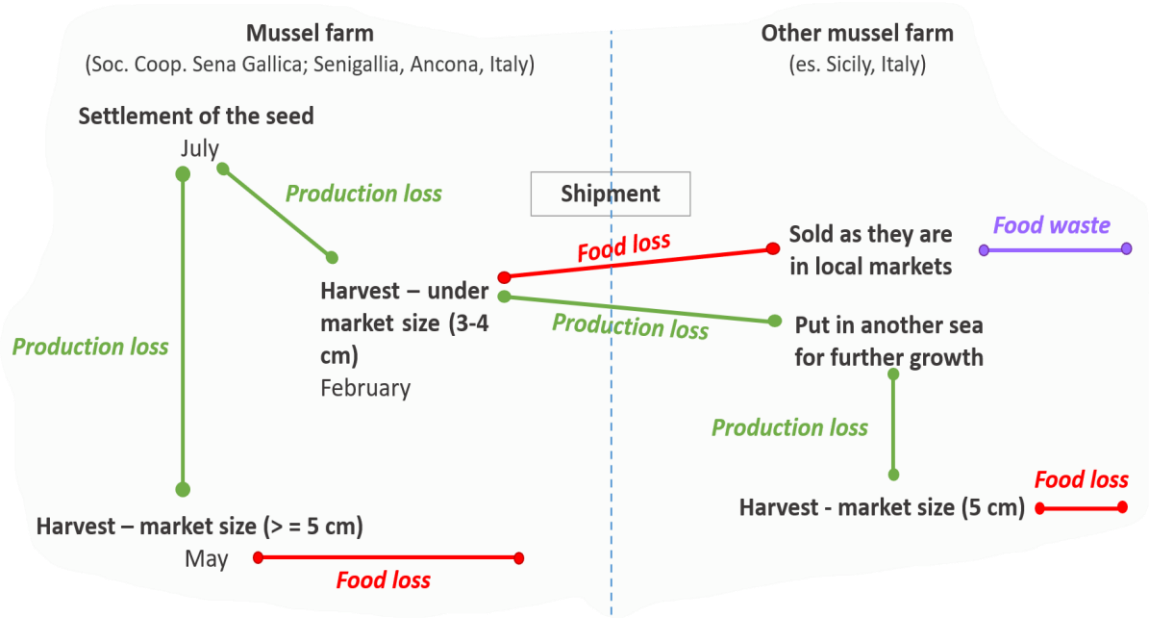

Figure 63. Scheme of the different steps within the productive cycle of the mussels' farm selected for the case study and the associated losses. Source: authors' own elaboration

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8.3.5.2 *Designing a sampling method for direct measurements collected in the mussels' farm*

Mussel cultivation is carried out using tubular mesh nets made of cotton (mussels' socks) which are then tied and vertically suspended from the horizontal long-lines, usually hanging down to a depth of about 4-7 meters. Normally, within the same farm, harvesting is not carried out on all lines at the same time, as production is staggered; therefore, there are lines at different stages of growth. In the case of mussels, measuring it is only carried out during the harvest phase, since it is "ready to harvest", and the sampling percentage is determined based on the weight of the sock production, to analyse at least 0.1% of the total production in harvest stage.

E.g. In one of the harvesting rounds, a production of 202,500 kg was collected (4.050 socks); therefore, losses were measured in a 210 kg sample (6 socks), thus reaching 0.1% of the total production.

Due to the staggered production and to capture the variability of losses across different locations within the same farm, it is recommended to take measurements during a few harvesting rounds, sampling socks located at different distances from the coast.

E.g. Three sampling sites were identified and named according to the size of the mussels' seeds at the beginning of the productive cycle: big, medium, and small. Sampling areas were distributed at different distance from the coastline (Figure 64).

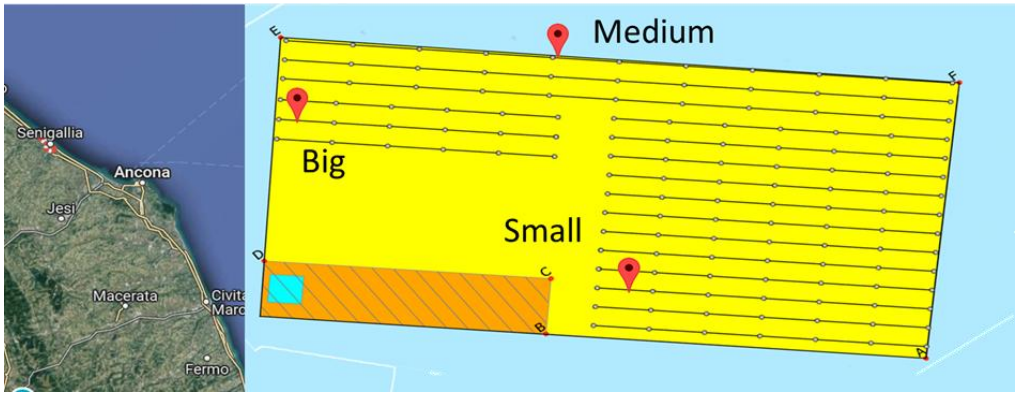

Figure 64. Sampling sites within the farm named Small, Medium, and Big according to the size of the seeds at the beginning of the productive cycle. Source: Università Politecnica delle Marche (UNIVPM)

8.3.5.3 *Measuring losses through direct measurements in the farm*

Following the definitional framework adaption to mussels, food loss measurements should be carried out at the harvest stage for sale.

Depending on the harvest (local or national distribution), mussels may undergo a cleaning process,:

- National distribution: mussels are not going to be cleaned. Food loss measurements will be based on counting and weighing both alive and dead specimens (including open shells). This allows production to be quantified in terms of live biomass per sample and enables calculation of the mortality rate.

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- Local distribution: mussels are going to be cleaned, and the cleaning process itself may cause damage, leading to food loss. To quantify this impact, whole socks of mussels should be weighed before and after the cleaning process. The cleaned product should then be analysed, counting and weighing both alive and dead specimens, recording the number of mussels damaged during cleaning, and calculating the mortality rate.

In either of the two cases, total weight, single animal weight and length, edible part percentage, presence of parasites, and the ratio of dead to alive specimens required to be measured in at least 0.1% of the production harvested in terms of weight

In the case of local distribution, dead specimens should be classified and weighed into three categories:

- **Dead mussels – under market size:** these are mussels that have died during the growth period and should therefore be considered productive losses rather than food loss.
- **Dead mussels – market size**: these are mussels that have died after reaching market size and should therefore be classified as food loss, in accordance with the food loss definitional framework adapted to mussels.
- **Broken mussels after cleaning**: these are mussels that have reached market size but were damaged during the cleaning process. They should be classified as food loss.

In addition, the case study proposes a method to measure productive losses during the growth cycle (Figure 66), as mussels are exposed to various factors—seasonal changes, variability in natural climatic conditions and seawater characteristics, and the potential presence of predators—that can cause specimen mortality. This method takes advantage of moments when farmers need to remove mussels to make changes in the cultivation structure, allowing intermediate samplings to be carried out. The same parameters as in the harvest quantification are recorded: total weight, single animal weight and length, edible part percentage, presence of parasites, and the ratio of dead to alive specimens. Dead specimens are considered productive losses and not food loss, since are not "ready to harvest". For more information, see Deliverable 4.2 of the FOLOU project.

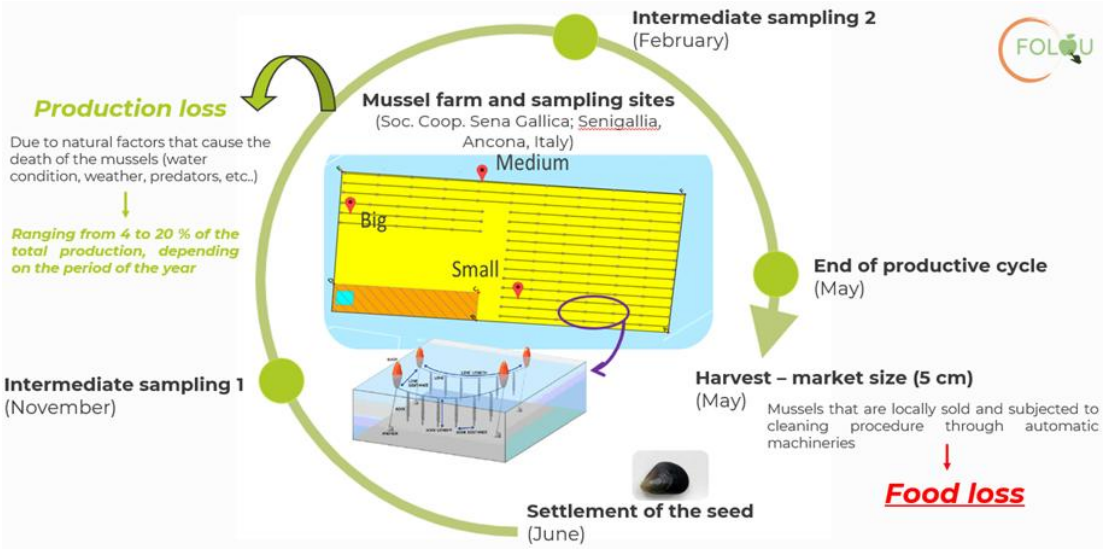

Figure 65. Scheme representing the whole productive cycle of mussels reared for the local distribution and the sampling points during the on-growing phase. All the losses measured during this phase accounted for production losses.

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8.3.5.4 Extrapolation of sample data

To extrapolate food loss data to the total farm production, the mortality rate of the sampled specimens must first be calculated:

$$FL\ mortality\ rate_{sample}(\%) = \frac{Dead\ market\ size\ mussels\ weight\ (kg)}{Sock\ weight\ (kg)} \cdot 100$$

In this context, the FL mortality rate functions analogously to the FL index used in other case studies. Specifically, the "*dead market-size mussel weight*" represents the food loss (FL), while the "*sock weight*" represents the total potential marketable production, including both live market-size mussels and dead market-size mussels (FL).

The median mortality rate of the sampled socks is used as the representative value to extrapolate losses at the harvest stage at the farm level:

$$Total\ FL\ (kg) = \frac{Marketable\ production\ (kg) \cdot Median\ FL\ Mortality\ rate\ (\%)}{1 - Median\ FL\ Mortality\ rate\ (\%)}$$

In the previous formula, "marketable production" corresponds to the total amount of product in a condition suitable for sale at the farm after harvesting and cleaning.

8.3.5.5 Illustrative measurements. Mussel case study in Italy.

Considering the results of one of the measurements carried out in the mussel case study (

Figure 66), the percentage of mussels ready to be sold derived from the cleaning procedure accounted for the 77.17 ± 3.63 % of the total sock' weight. The second most represented fraction was the mussels seed that accounted for 14.85 ± 2.87 % of the total sock' weight. The mussels seed represents an interesting fraction: in fact, despite they don't constitute a sellable product, seeds are recovered by the farmer and are used as starting point for the following productive cycle. The dead mussels under market size (0.85 ± 0.12 %) constituted normal production losses since these were specimens that died for natural reasons (environmental parameters or presence of predators) during the previous months. The real food loss sources were represented by the dead mussel harvested at market size (2.25 ± 0.53 %) and by mussels irreparably damaged by the cleaning procedure (3.27 ± 0.67 %) which affected the total farm production for 0.36 and 0.68 %, respectively. Differently, slightly damaged mussels, which accounted for 1.62 ± 0.29 % of the total sock' weight, were characterised by minor shell fractures that did not impair the survival from harvesting to the consumer. The discrimination of broken mussels according to the degree of the damage allowed to not overestimate the food loss sources introduced by the automatic cleaning machine. These findings highlighted the major food loss sources that affected the productive cycle analysed within the present case study and could represent a starting point to be compared with other farms and to optimise the supply chain, minimising losses.

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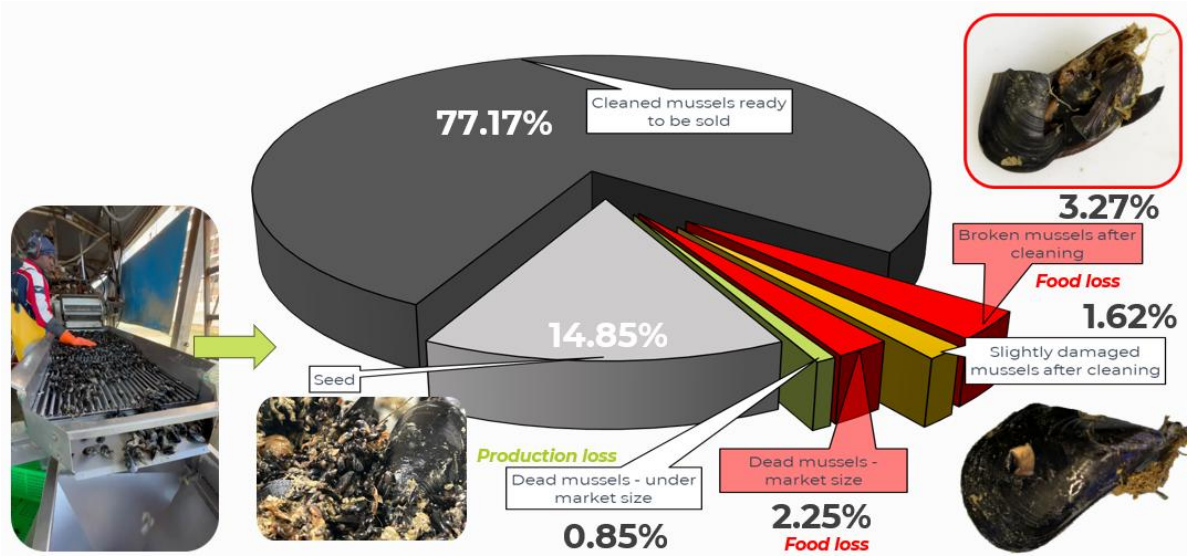

Figure 66. Results obtained from the automatic cleaning procedure conducted on mussels' sock at harvesting for local distribution.

8.3.5.6 Measuring costs

On average, sampling requires a full day for two people, including both on-board and transportation time. Laboratory analysis takes three people three full days, while data analysis involves two people over the course of one week.

8.3.5.7 Adaptation to other food commodities

This loss quantification methodology can hardly be applied to other food typologies, primarily because of the unique production cycle, farming methods, and harvesting procedures associated with mussels, particularly when compared to other animal-derived commodities. The main source of food loss is generated by the cleaning process, which is a distinctive step in mussel production, which, however, remains essential for a fast process necessary for the final sale. Moreover, since mussels are harvested and transported live, unlike other aquaculture species, it introduces a different set of variables for maintaining product quality and safety throughout the cold chain.

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8.3.6 Measuring food loss in salmon

The following section outlines the key considerations for measuring food loss in salmon (*Salmo salar)*, based on the case study conducted by the Norwegian Research Centre (NORCE).

It includes the adaptation of the food loss definitional framework to salmon; considerations regarding the measurement methodology applied to salmon; a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.6.1 Introduction. Salmon production process.

To understand the process of measuring food loss in salmon, it is first essential to grasp the production system of salmon in aquaculture (specifically focus on Norwegian salmon). The production of farmed salmon can be organized in six main stages that spans the production of eggs in stage 1 to the final processing of the consumer products in stage 6 (Figure 68). The focus of the case study is on stage 3, which is the grow-out stage in the sea where the fish is reared till marketable size. The grow out stage comprises 12-24 months. Due to an increasing trend in Norwegian aquaculture of having an extended "post-smolt" stage prior grow-out stage, the grow out stage tends to be below 20 months long.

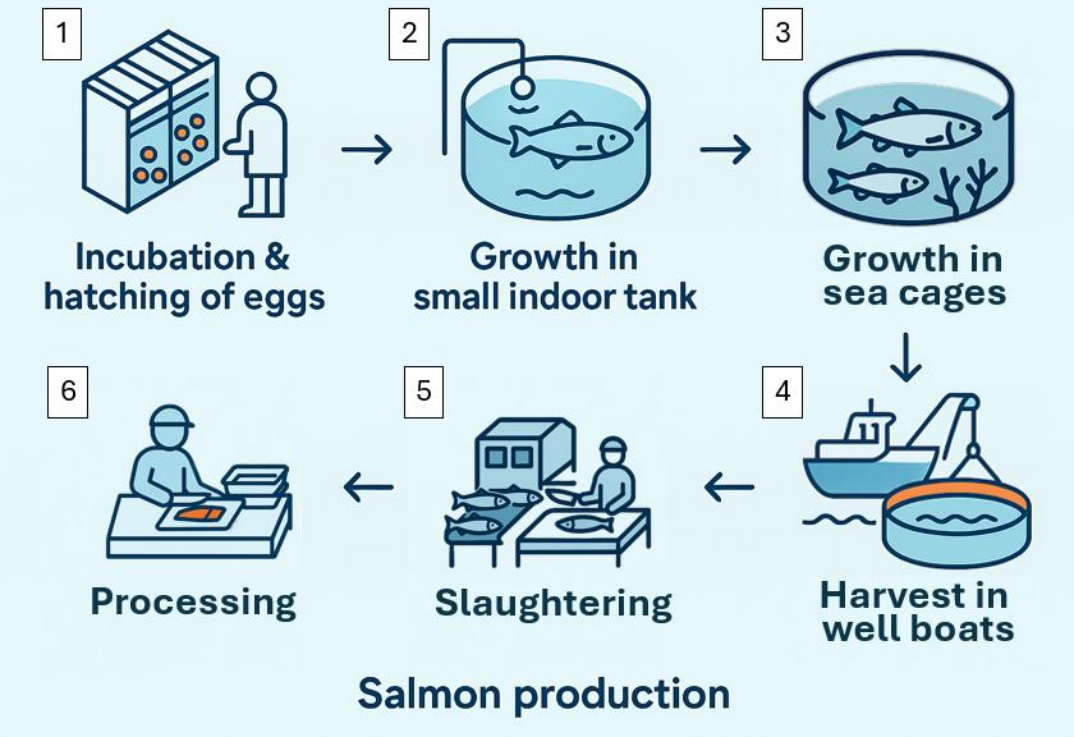

Figure 67. The salmon production cycle. Source: author's own work, created using AI tools.

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8.3.6.2 Adaptation of the food loss definitional framework to salmon

The general FLDF adapts to the case of salmon, but with some particularities:

Following representative slaughter weight, this study establishes 3 kilograms as the threshold at which salmon transitions from production phase to being "ready to be harvested" as food. This cut-off weight reflects the market preference for salmon predominantly sold above 3 kilos, though this threshold may be subject to revision based on evolving market conditions.

A challenge arises from the fact that salmon remain in the same sea cages from approximately 100-250 grams (or in the case of post-smolt starting from around 400 to over 1 kilo) through to harvest weight of typically 4-5 kilos (but can also reach weights over 10 kilos). This means that within a single cage, there is a period during which losses are classified as production losses (less than 3kg), followed by a period where losses constitute food loss (3kg and above), with the transition between these categories occurring while fish remain in the same physical location.

Figure 69 shows a stylized timeline for the grow-out stage in the sea. When smolt is released in the sea at size of say 100 grams, it can take around 12 months before the fish reaches a weight of 3 kilos. The exact time will be dependent on a number of factors such as sea temperatures, feeding regime, water quality etc. When the fish has reached 3 kilos losses are no longer considered as production losses, but food loss. Note that “harvesting period” represent the period when salmon farmers normally decide to harvest and slaughter the fish. However, for an individual farm the harvesting period is not spread out over this period. The entire batch is normally harvested and slaughtered during a few days.

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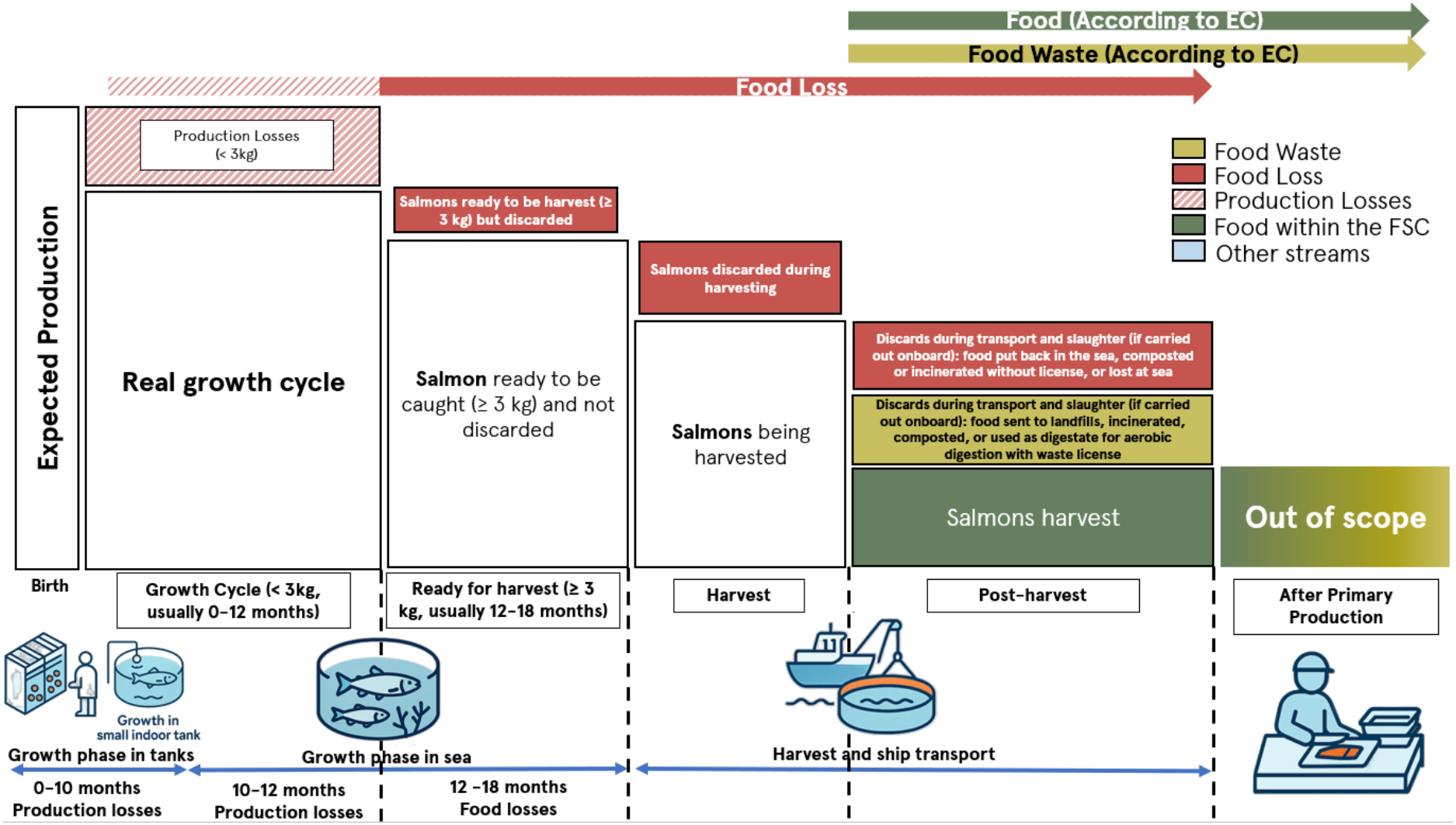

Figure 68. Food loss definitional framework adapted to salmon case

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8.3.6.3 Measuring salmon food loss

Unlike other case studies in the FOLOU project, the salmon case study uses a food loss quantification methodology based on the analysis of existing records. This approach is possible because Norwegian salmon producers already operate established systems to record and quantify production losses in salmon farming, as required by Norwegian authorities. Specifically, production loss counting is a regulation tied to the salmon production license[15]. Production losses, of which share of losses of fish larger than three kilos are redefined as food losses in the FOLOU project, are measured using various metrics, including the number of fish lost and the size of biomass loss (in kilos). Table 45 gives an overview of biomass data collected by the authorities, which allows calculation of average weight of the fish in the pens and can therefore track when the fish exceeds 3 kilos.

Table 45. Overview of biomass data salmon farmers report to the Norwegian Directorate of Fisheries.

Category	***Data Field***	***Unit***
Time Period	Year	-
	Month	-
Location	Location number	-
	Location name	-
	Cage/pen volume	m^3
Fish Characteristics	Year class/cohort	-
	Fish species ID	-
Fish Stocking	Released smolt	Count
	Total released	Count
Inventory	Fish inventory/stock	Count
	Biomass	kg
Feed	Feed consumption	kg
	Feed type ID	-
Losses	Loss - dead fish	Count
	Loss - discards	Count
	Loss - escapes/escapees	Count
	Loss - other	Count
Harvest/Removal	Harvest - slaughter	Count
	Harvest - slaughter	kg
	Harvest - live fish	Count
	Harvest - live fish	kg
Site Management	Fallowed/resting	Status
	Moved to/transferred to	Location

The equation below shows the food loss (FL) calculation for salmon. The four loss categories that the Norwegian Directorate of Fisheries use for registering losses are included in the

[15] *Forskrift om drift av akvakulturanlegg (akvakulturdriftsforskriften)*, FOR-2008-06-17-822, Norwegian Ministry of Trade, Industry and Fisheries, Section 44

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formula. Mortality represents the fish that die during the production stage through harvest. This includes deaths due to disease, handling stress, environmental factors, parasites, and other cause. Mortalities are by far the largest factor of food loss in salmon farming. Escapees are the fish that escape from sea cages or other containment systems, which do not only represent food loss, but also introduce ecological risks as the escaped salmon may interact with wild populations. Discards are the fish that are slaughtered but not used for human consumption due to deformities, wounds, or poor quality. And finally, the "others" is a category created to offset accounting of too high or too low losses registered at individual farms. Accurate numbers of actual farm losses can only be verified at the time of harvest, as the final numbers of fish harvested can then be compared to the initial number of smolt that was put to sea.

$$FL_t = \left[\frac{(\#Mortalities + \#Escapees + \#Discards + \#Others)}{\#Slaughter} \times (share\ fish\ losses\ > 3\ kilos)\right] + \frac{\#Discards\ post\ harvest}{\#Slaughter}$$

This information provided by public authorities can be complemented with data from various private platforms, which contain a large volume of aggregated information with a higher level of granularity than that collected by public administrations. An example of such a database that contains useful data for analysing food loss is AquaCloud. This database not only gathers information on the magnitude of the food loss problem but also the causes associated with these losses. Specifically, AquaCloud collects data on over 360 causes related to losses.

In this regard, share of losses >3 kg is calculated using AquaCloud data in the following manner:

$$Share\ fish\ losses > 3kg = \frac{(\#fish\ losses > 3kg)}{(\#fish\ losses\ in\ total)}$$

There are two points in time when all the salmon in a cage is counted: 1) when the smolt/post-smolt salmon is transferred to cage for grow-out and when the fish reach market sizes and is harvested. These two events correspond to stage 3 and 4 in Figure 68. These counting events provide the starting number and the final harvestable number of fish in the cage. The difference between these two numbers represents the total production losses during the grow out stage.

In between the beginning and end of the production cycle, salmon farmers are mandated by governmental regulations to count any losses that occur daily. In current loss control systems, daily mortalities are recorded in the freshwater brood, parr, and smolt rearing tanks (production losses) through the manual removal of dead fish using nets. In the case of sea cages, an integrated pumping system collects the dead fish and automatically records and counts them. As mentioned in the definitional framework, there is a time range in sea cages during which the fish have not yet reached the stage of being "ready to be marketed". This period normally ranges from 10 to 12 months. Since fish raised within the same sea cage generally have similar average weights, mortalities recorded between months 10 and 12 are considered productive losses. By contrast, mortalities recorded after the fish are considered to have reached a weight of 3 kg, which usually occurs from month 12 onwards, are recorded as food loss, specifically pre-caught food loss. It is these routines that allow us to create a time- and cause-profile of losses in the grow-out stage.

The vast majority of the control and counting points are automated, meaning that the loss measurement system for this type of product does not require methods for on-site

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quantification. Instead, it relies on obtaining records, analysing data quality, and interpreting all the collected information.

8.3.6.4 Illustrative measurements. Salmon case study in Norway.

Figure 69 shows losses for a salmon producer that farms both organic and conventional salmon. The producer has provided us with data on losses for four generations of salmon production cycles in the grow-out stage, as shown in the figure. The final generation was not completed (i.e., not been harvested yet) at the time the data was shared. As can be seen there is considerable variation between each generation in when and why losses occur.

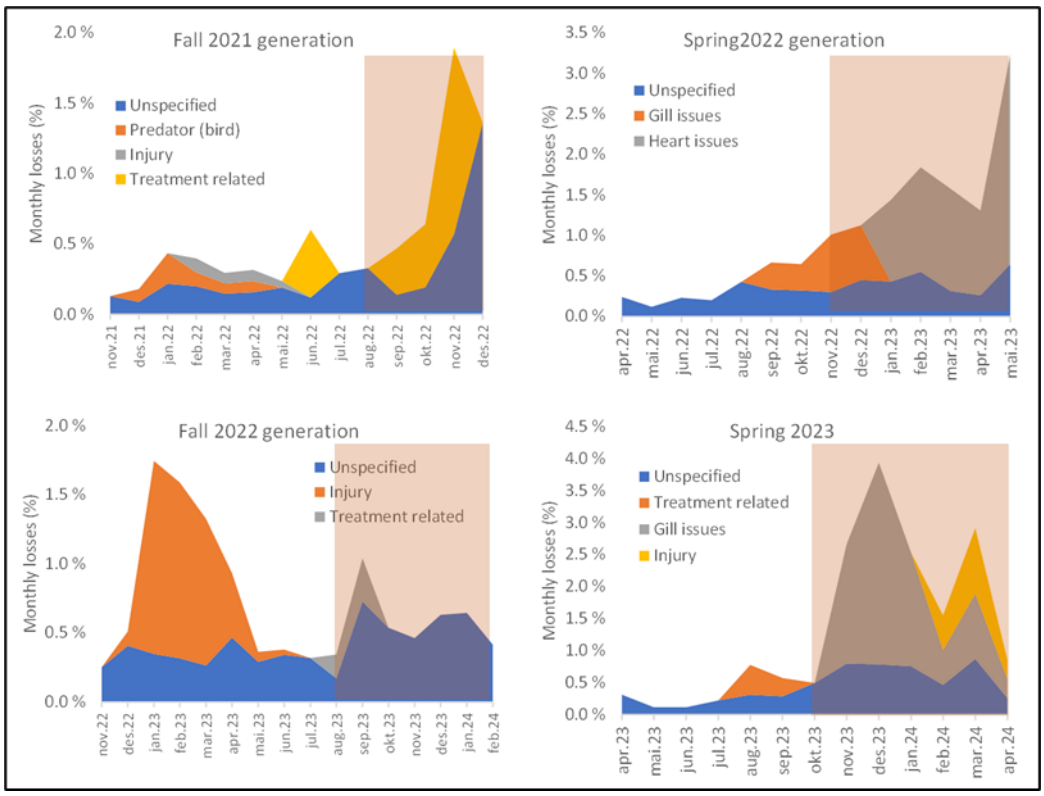

Figure 69. Losses in the production cycles of four generations of organic salmon (note: Spring 2023 generation production cycle not completed). The pinkish area represents food loss based on a cut-off weight of around 3 kilos. (Individual producer, anonymous)

The food loss categories presented previously and the losses presented from an example farm above highlight the infectious diseases and treatment as a major contributor for salmon mortality.

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8.3.6.5 *Measuring costs*

Since this methodology for measuring food loss in salmon is primarily based on mortality records that producers already collect due to legal requirements, the additional costs of measurement are purely analytical. For a single farm over a single month, the data analysis itself would be relatively straightforward. Assuming the farm already records daily mortalities and data is organized in a structured format, a researcher could estimate monthly food loss within a few hours of work: downloading or receiving the data, checking for quality issues, applying the food loss formula, and producing a summary. The main time cost is not the analysis per se: establishing data access agreements, understanding how data is recorded, and cleaning data. For a first-time application at a new farm, maybe one to two days in total; for subsequent months at the same farm, a few hours.

It should be noted that, in the case of Norway, the Directorate of Fisheries data is public and freely accessible. On the other hand, as mentioned, there are specialised companies for salmon loss traceability, such as Aquacloud, which also provide very detailed loss data shared between farms, but under a paid subscription.

If the facilities are not prepared for loss counting and direct measurement by workers is required, the costs of data analysis must be added to the costs of collecting the dead fish daily, as well as the necessary materials and equipment. However, as considerations relating to biosecurity and fish health mean that dead fish must be removed from the cages, this process can also be used as an opportunity to count and weigh the dead fish.

8.3.6.6 *Adaption to other food commodities*

The framework for counting losses in Norwegian salmon aquaculture could be adapted to other aquaculture production systems, particularly those operating in controlled environments with regulatory oversight. Marine aquaculture species such as sea bass and sea bream in the Mediterranean could directly benefit from similar loss categorisation systems, daily mortality monitoring, and biomass tracking protocols. The salmon production system shares traits with other intensive animal production systems like terrestrial livestock operations, where poultry, swine, and cattle production. However, as aquaculture systems operate below sea surface loss tracking is more complicated than in terrestrial animal production. Nonetheless, the detailed cause classification system might offer a template for developing sector-specific loss taxonomies that capture the relevant biological, environmental, and management factors affecting different species. The methodology's strength lies in its integration of mandatory reporting, standardised metrics, and technological solutions for real-time monitoring—principles that could enhance food loss measurement across different fish aquaculture systems.

For aquaculture species where strict food loss and production loss separation proves impractical, several alternative approaches merit consideration. Establishing size-based thresholds at the population level (such as "when 50% of the population exceeds market size") could provide workable approximations. For systems where distinguishing food loss from production loss is prohibitively complex, measuring total losses from stocking to harvest and applying estimated allocations based on growth curves may be more practical than attempting precise classification. The FOLOU framework's principles can be maintained while adapting specific implementation details to local contexts, species characteristics, and available resources, maintaining methodological consistency in defining food loss while allowing operational flexibility in measurement approaches.

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The application of this methodology relies on the existence of reliable mortality records for farmed salmon, with a sufficient level of detail to allow the identification of food loss. At the European level, Scotland is the only other major salmon farming nation with regulatory requirements broadly comparable to those in Norway. Scottish farms are required to report disease events and mortality through Marine Scotland's Fish Health Inspectorate under the Aquaculture and Fisheries (Scotland) Act 2013. However, the regulatory framework does not require daily reporting of losses with the same level of detail as in Norway.

Ireland also has reporting obligations under the Sea-Fisheries and Maritime Jurisdiction Act, although these operate at a lower level of granularity.

At EU level, the Animal Health Law (Regulation (EU) 2016/429, in force since 2021) requires Member States to monitor the health status of aquaculture animals, but it does not mandate the daily reporting of production losses. Similarly, Commission Regulation (EC) No 762/2008 on aquaculture statistics requires reporting of production volumes rather than a detailed categorisation of losses. As a result, the wider application of this methodology across other countries or at EU level would likely require a greater degree of regulatory harmonisation.

Nevertheless, it is important to note that the quantification of food loss does not depend exclusively on the existence of legal reporting obligations. In principle, any fish farm could allocate resources to measure such losses. In these cases, the methodology would need to be adapted to allow for manual quantification of losses through the collection, counting and weighing of dead fish, or alternatively through the installation of automated systems designed to measure and record mortality.

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8.3.7 Measuring food loss in the meat sector

The following section outlines the key considerations for measuring food loss in the meat sector, with a particular focus on beef production, based on the case study conducted by the University of Limerick in Ireland and in Flanders (Belgium).

It includes the adaptation of the food loss definitional framework to meat production; considerations regarding the measurement methodology applied to meat; extrapolation of sample data; a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.7.1 Adaptation to Definitional framework

The FLDF for meat has been adapted from the general framework, including considerations to define the moment "ready to harvest" and the transition between food loss and FW.

The definition of "ready to harvest", which establishes the point at which animals are physiologically and economically ready for slaughter (in beef systems) as the baseline for food loss measurement, requires careful calibration to each livestock systems. In the Irish case, for beef cattle, readiness criteria were established based on target finishing weights (typically 500-650kg liveweight), age parameters (18-30 months for steers), and market specifications including fat class and conformation scores under the EU carcass classification system- EUROP.

A decision framework was developed to categorise losses based on final destination pathways: carcass downgrades resulting in incineration or landfill disposal were classified as food loss, while products redirected to by-product channels (such as pet food manufacturing or pharmaceutical applications) were not counted as food loss, recognising their continued utility within the broader food system. As the diagram (Figure 70) below shows, it was necessary to create a distinct point in which the animal became food- this was determined to be once the carcass had passed the post-mortem test. The reason for this being that the carcass must be classified and graded by EU standards (EUROP scale) before the meat can be butchered further. Therefore, discards after the product have passed the post-mortem test would be considered FW.

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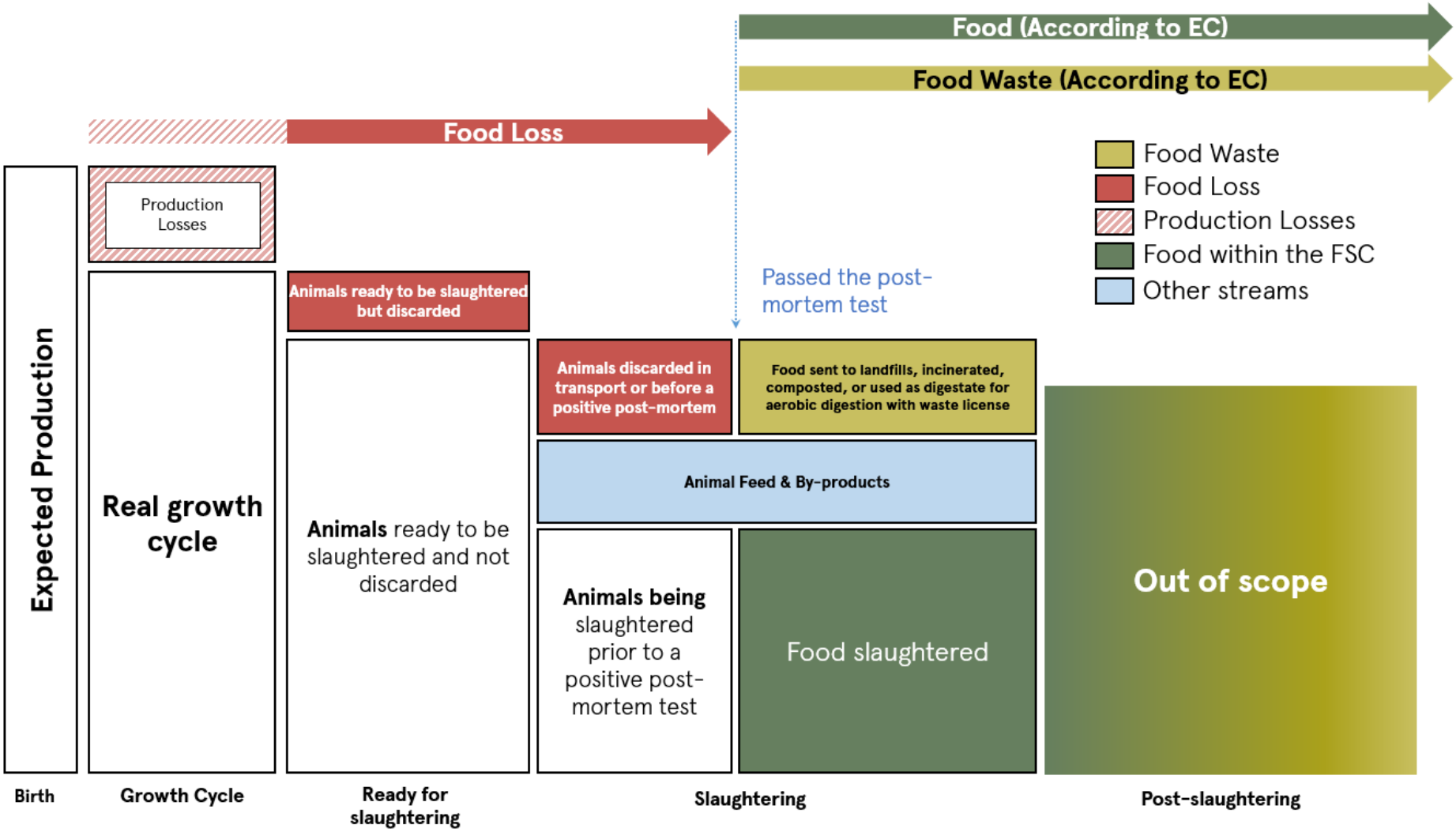

Figure 70. Food loss definitional framework adapted to meat

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8.3.7.2 Measuring and data extrapolation to farm

Based on the experience from the case study at the University of Limerick, it has been observed that the direct measurement of food loss is unfeasible due to the characteristics of the meat production process. For this reason, it is recommended that food loss be measured through records and interviews with farmers, thereby enabling the development of a comprehensive food loss diagnosis. Table 46 shows the formulas used to calculate food loss at each stage of the production process.

Table 46. Flows considered to be measured

Stage	Data Sources	Calculation (example)	Validation (via interviews)
Production Loss- animals not yet considered food i.e. do not meet "ready for slaughter" criteria	There isn't a single official "FL percentage loss for meat" published in Irish statistics- CSO mainly focuses on supply and uses rather than losses. However, we can derive a basic percentage loss estimate at a national level using figures available.	$Production\ loss\ (\%)$ $= \frac{Total\ meat\ supply - Meat\ consumed}{Total\ meat\ supply} x$	Farmers- Any losses/deaths that occur before ideal weight etc. or calf deaths
Ready for slaughtering FLOW 1: On Farm	• CSO- Livestock surveys • Eurostat-Farm Structure Survey • IFA report on disease/weather impact on grazing	$FL\ on\ FARM\ (kgs)$ $= (Number\ of\ Deaths\ x\ Average\ Liveweight\ at\ Death$	Farmers- discuss disease outbreaks, fertility issues, weather stress
Slaughtering FLOW 2: Carcass Loss	• Bord Bia- export reports (meat) • Eurostat- Food balance sheets (processing waste) IFA- data on spoilage during chilling/transport	$FL\ carcass\ (kgs)$ $= (\ Carcass\ Intake\ -\ Edible\ Output)$ $- Valorised\ Byproduct$	Abattoirs and inefficiencies observed in processing
Slaughtering 2 (Processing and Storage) FLOW 3: Blood, Casings, Offal	• Bord Bia- export reports (meat) • Eurostat- Food balance sheets (processing waste) IFA- data on spoilage during chilling/transport	$FL\ Blood\ (a), casings(b), offal(c)\ (kgs)$: $= (\text{Volume Available at Slaughter}$ $- \text{Volume Destined for Human Consumption})$ $\times \text{Waste Treatment Fraction}$	Abattoirs and inefficiencies observed in processing
TOTAL LOSSES	$Total\ Food\ Loss\ (kgs)$: $= \text{Flow 1} + (\text{Flow 2} \times \text{Waste Treatment Fraction}) + (\text{Flow 3a} + \text{3b} + \text{3c} \times \text{Waste Treatment Fractions}$		Total losses based on breakdowns of each potential source/flow of food loss in Slaughtering

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Total Meat Supply: The total quantity of meat available in a given country or region over a defined period. It is typically calculated as domestic production (from slaughter) + imports − exports ± changes in stock. It represents the overall pool of meat entering the supply chain before any losses are accounted for. *Sources:* The CSO's Meat Supply Balance publication provides annual estimates of total meat supply in Ireland, covering beef, pig, sheep, and poultry. Central Statistics Office At EU level, the European Commission's Agricultural Markets balance sheets and Eurostat's agricultural production statistics track meat supply by Member State. Eurostat

Meat Consumed: The quantity of meat actually consumed by humans (also called "human consumption" or "domestic use"). It is derived by subtracting exports, processing losses, waste, and stock changes from total supply. It is often expressed in per-capita terms. *Sources:* The CSO's Meat Supply Balance reports per capita annual human consumption figures for Ireland, broken down by meat type. Central Statistics Office At EU level, Eurostat's food balance sheets and the FAO Food Balance Sheets provide harmonised consumption estimates across Member States.

Livestock Mortality Before Slaughter: The number (or weight equivalent) of animals that die on-farm before they ever reach slaughter — due to disease, injury, adverse weather, or other causes. These animals never enter the slaughtering system and represent a pre-slaughter loss. *Sources:* In Ireland, the CSO's Farm Structure Survey and the Eurostat Farm Structure Survey collect data on livestock numbers and on-farm deaths. The IFA (Irish Farmers' Association) also reports on disease outbreaks and weather-related mortality. At EU level, Eurostat's livestock statistics and national agricultural census data are the standard references.

Total Herd: The total number of animals present in a country or region at a given point in time, regardless of whether they are destined for slaughter. It serves as the denominator for calculating pre-slaughter mortality rates. *Sources:* In Ireland, CSO livestock surveys track cattle, sheep, and pig numbers, with slaughter data compiled monthly from DAFM-approved meat establishments and local authority facilities. Central Statistics Office At EU level, Eurostat publishes harmonised livestock population statistics under Regulation (EC) No 1165/2008, covering all Member States.

Condemned Carcasses: Carcasses (or parts thereof) that are declared unfit for human consumption following veterinary inspection at the slaughterhouse — either at ante-mortem (before slaughter) or post-mortem (after slaughter) inspection. Condemnation can be due to disease, contamination, injury, or other health concerns. *Sources:* Under EU Regulation (EC) No 854/2004, official veterinarians at slaughterhouses must identify specified disease lesions, and detection of certain conditions results in full condemnation of the carcass. Springer In Ireland, condemnation data is held by DAFM's official veterinary service. While EU law requires significant meat inspection findings to be reported back to producers, there is no legal requirement for a standardised recording system for condemnation reasons across Member States, PubMed Central meaning data quality and availability vary by country.

Total Slaughter: The total number of animals slaughtered (or the total carcass weight produced) in approved facilities over a given period, including both those passing and failing post-mortem inspection. It is the gross input into the slaughtering stage. *Sources:* In Ireland, the CSO publishes monthly Livestock Slaughterings data covering cattle, sheep, and pigs slaughtered at DAFM-approved meat establishments and local authority facilities, compiled under EU Regulation (EC) No 1165/2008. Central Statistics Office At EU level, Eurostat collects carcass weight data from slaughterhouses, where meat is deemed fit for human consumption. Eurostat

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Carcass Intake: The total weight of carcasses entering a meat processing or storage facility after slaughter and initial dressing. It is the starting point for the processing and cold-chain stage, and corresponds to the gross raw material available before cutting, boning, trimming, and further processing. *Sources:* In Ireland, Bord Bia export reports and DAFM plant-level data capture carcass weights entering processing. At EU level, the European Commission's Agricultural Markets balance sheets provide simplified estimates of production, trade, and apparent use of meat at country level, European Commission from which carcass intake figures can be approximated. Individual processing companies are also required to maintain HACCP records under EU food hygiene regulations (EC) No 852/2004 and 853/2004.

Edible Output: The quantity of meat product that exits the processing and storage stage in a form fit for sale or consumption. It is lower than carcass intake due to losses from boning, trimming, cutting waste, cold-chain spoilage, and processing inefficiencies. The difference between carcass intake and edible output represents the processing-stage food loss. *Sources:* This is the hardest parameter to capture at a national aggregate level. In Ireland, Bord Bia processing waste data and IFA cold-chain spoilage reports are partial sources. At EU level, Eurostat collects FW data across the supply chain — including the processing and manufacturing sector — under Commission Delegated Decision 2019/1597, using mass balance methodologies reported by Member States. Eurostat The FAO Food Balance Sheets also provide retail-weight estimates that can be used to back-calculate edible output from carcass weight figures.

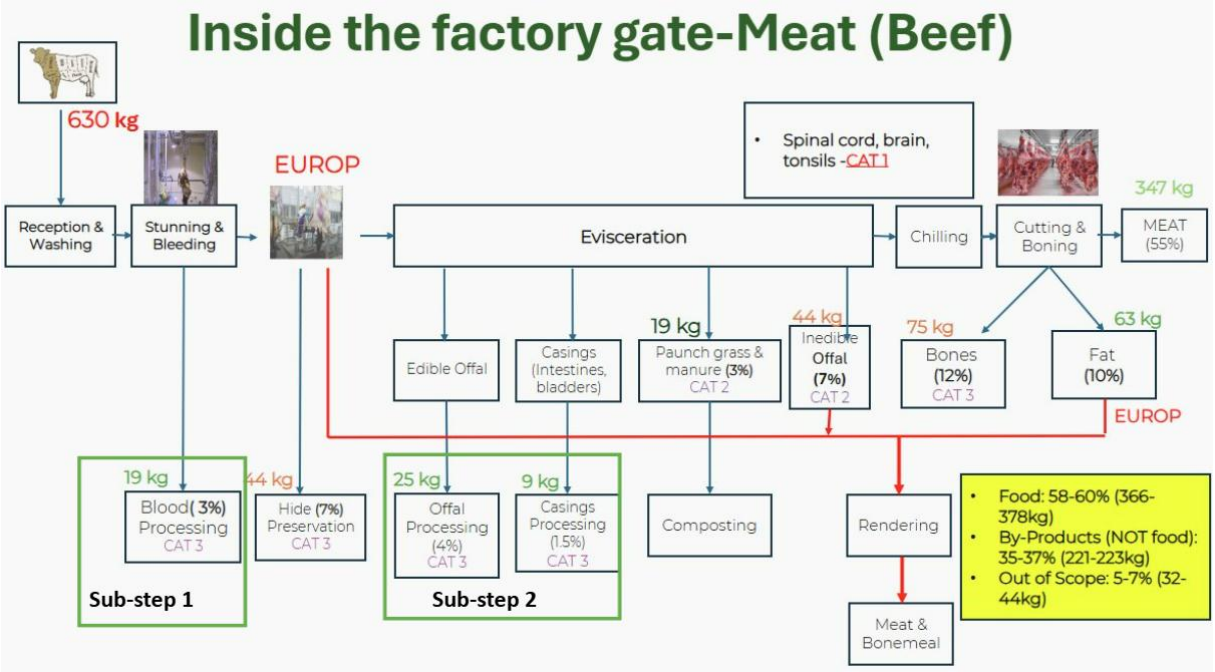

Figure 71. The flows within the slaughterhouse where food loss may occur.

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8.3.7.3 *Illustrative measurements. Meat case study in Ireland.*

Regarding the results, Table 47 below summarises the information presented above, highlighting each stage and the associated losses. An additional initial row is also included, which falls under production losses.

Table 47. Main food loss results for Irish meat across the main stages (Mean results from 2018-2025).

Stage	Loss Category	Magnitude	Sub-Components / Notes
Production losses	—	Minimal losses observed	Mainly handling effects rather than quantifiable losses
Ready for Slaughter (pre-slaughter food loss)	Carcass Rejection & Downgrades	2–4% of carcasses	- Bruising due to transport: 45% of rejections - Residues: 25% - Export spec failures: 20% - Other quality issues: 10%
Slaughtering 1	Offal Oversupply / Market Limits	8–12% of edible offal	15–20 kg per animal diverted (peak season)
TOTAL		**10-16%**	**Cumulative effect**

Based on the loss categories identified in this study, total food loss in the primary production stage of the beef sector in Ireland can be approximated at 10-16%% of potential edible output. This percentage range does not include production losses, as it is very case/farm specific as to the losses that occur here.

8.3.7.4 *Measuring costs*

Data collection and analysis required a three-person team: a primary investigator, a secondary investigator and a post-graduate student. Over the course of the fieldwork, we devoted approximately 74 hours in total to the interview process, including scheduling, travel, conducting the semi-structured interviews, and recording the responses. Subsequent transcription and integration of the interview data with registry information were carried out by the post-graduate student, with oversight and validation checks performed by the primary and secondary investigators.

8.3.7.5 *Adaption to other food commodities*

Sheep and pig meat production share fundamental similarities with beef systems, including comparable slaughter-readiness indicators (weight, age, condition score) and similar regional variability in carcass utilisation patterns. The seasonal nature of many sheep operations, particularly in hill farming systems, would require an adjustment to define the optimal threshold for what is considered “ready to slaughter”.

Sheep systems exhibit higher pre-slaughter mortality rates than beef, particularly during lambing seasons, requiring enhanced focus on production phase losses. In the Irish sheep and pig sectors, particularly among organic and agroecological producers who rely on direct marketing channels (e.g. farm gate sales, local butchers and farmers’ markets), the conventional mechanisms used to monitor post-harvest losses don’t fully apply. Typical post-harvest loss tracking frameworks are designed around centralised abattoirs and

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integrated processing plants, where details such as carcass data, yield information, grading outcomes and quality-based rejections are documented regularly. However, in the organic and agroecological structured farms, the carcasses are often moved through smaller local abattoirs, on-farm butchering facilities or short, decentralised supply chains, where such data is not recorded as consistently or accurately.

In sheep meat systems, this decentralisation means that losses, such as carcass downgrades, packaging failures or spoilage (e.g. at a farmers' market) often goes untracked. This can also be observed in Irish organic and rare-breed pig production, where small herd sized, batch processing and diverse product lines (speciality products, cured cuts etc.) create multiple potential points where quantitative loss data is lacking or even absent. In direct pork sales, producers might have records of fat-to-lean ratios, or information on the fate of unsold cuts, but none of this information is systemically captured in existing national reports.

Administrative capacity is often limited on smaller organic and agroecological farms, and because their marketing channels tend to bypass much of the formal meat supply chain, the tracking of post-harvest losses in both pig and sheep systems requires modified, farmer-friendly approaches that allow an accurate reflection of shorter supply chains. This could include, for example, a simplified on-farm loss template, standardised data logs in smaller abattoirs, inventory audits and possibly a digital recordkeeping system tailored to the diverse product mixes these animals provide.

Poultry systems present unique challenges due to rapid production cycles and high susceptibility to disease-related losses. The short timeframe between RH status and processing (typically days rather than months) creates compressed decision-making windows and heightened loss risks. At the level of the definitional framework, this sector would be highly adaptable, however in terms of loss ratios this would be a food commodity where greater differences would occur compared to beef, as there is far more risk of mortality and carcass downgrades in such tight windows. The poultry sector would also differ in terms of losses relative to the sheep and pig industry, but as vastly different as beef and poultry would. Commercial poultry systems operate as highly standardised, closed production systems, where flock inputs, feed conversion, mortality and slaughter outputs are tightly monitored. This structure allows opportunities for highly precise tracking of loss, but the same strict biosecurity protocols that protect flock health can constrain how this data is collected.

The prevalence of automated environmental monitoring, continuous flock performance metrics, and digital slaughterhouse grading systems suggests that poultry systems generate high-resolution datasets that could, in theory, support more precise tracking of post-harvest losses. As a result, the poultry sector serves as a conceptual contrast point, highlighting how data-rich environments shape what a loss assessment framework must be capable of capturing.

However, the same strict protocols that underpin modern poultry production also constrains many conventional data collection approaches, particularly involving on-farm researcher presence, or even routine observational auditing. These limitations inform potential adaptations if the framework by emphasising methods suitable for remote, low-contact or fully automated data environments. The poultry case could represent a methodological stress-test, illustrating how commodity-specific structures, including integrated processing, closed housing and legally mandated biosecurity necessitate flexible data collection pathways within the framework analysis. Incorporating these considerations ensures that a final framework would be applicable across diverse European meat systems-from technologically intensive poultry units, to decentralised, mixed-market sheep and pig operations.

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8.3.8 Measuring food loss in the milk sector

The following section outlines the key considerations for measuring food loss in the dairy sector, with a particular focus on milk production, based on the case study conducted by the University of Limerick in Ireland and in Flanders (Belgium).

It includes the adaptation of the food loss definitional framework to milk production; considerations regarding the measurement methodology applied to milk (sampling process, direct measurement, and extrapolation of sample data); a brief presentation of the results from the case study; and the potential adaptation of this methodology to other food commodities.

8.3.8.1 Adaptation to Definitional framework

The FLDF has also been examined, given the specific requirement for a series of control tests, particularly those carried out during the storage stage, prior to processing, to be approved before the product can be deemed fit for human consumption and thus formally enter the food domain. The starting point is the actual milking process, since all preceding stages are understood to relate primarily to the cow's breeding and husbandry processes, which are more closely aligned with production losses. There is effectively no intermediate period between "ready to be milked" and the milking itself. For these reasons, an adaptation of the general food loss framework to the specific context of dairy products has been proposed.

Thus, food losses in the dairy sector are defined as those occurring from milking point until the first step of processing, after passing the two mandatory control tests.

The diagram below in Figure 72 shows the definitional framework for quantifying dairy loss and waste in the primary production sector, as determined by using the perceptual interviews, as well as literary analysis and conducting with industry experts.

Significant modifications to the standard FOLOU approach were necessary to accommodate the unique characteristics of Irish livestock systems. In dairy operations, pre-lactation culling presented a particular challenge for classification. Following extensive consultation with industry experts and review of international best practices, pre-lactation culling (including death during the dry period or forced culling due to health issues before lactation begins) was classified as production loss rather than food loss, recognising that these animals had not yet reached their productive potential.

Conversely, milk disposal occurring after the ready to harvest (RH) point due to factors such as mastitis treatment, somatic cell counts violations, or tank contamination was classified as genuine food loss. This distinction proved crucial in accurately quantifying waste streams and identifying intervention opportunities.

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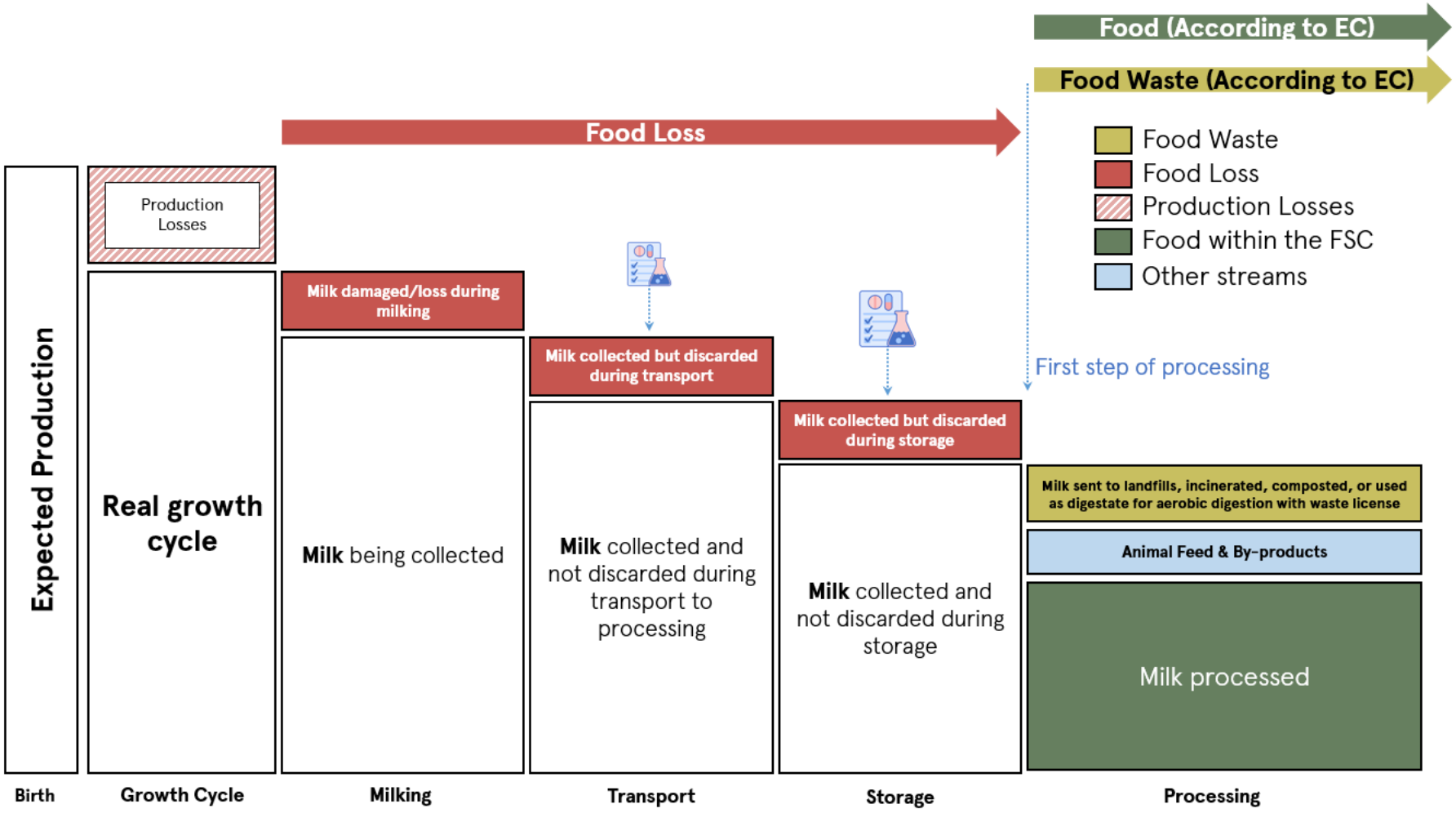

Figure 72. Food loss definitional framework adapted to milk. Icons in "transport" and "storage" stages represent the food safety mandatory control tests.

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8.3.8.2 Designing a sampling method

Similarly to the meat one, the milk case study has addressed the challenge of quantifying food losses in a sector whose specific characteristics make direct measurement unfeasible. Instead, data must be obtained through the use of records and interviews with sector stakeholders, thereby enabling the development of a comprehensive food loss diagnosis.

Thus, the Irish case studies employed a comprehensive mixed-methods approach designed to bridge the gap between theoretical food loss frameworks and practical agricultural realities. This methodology combined qualitative insights from semi-structured interviews in Ireland and Belgium, with extensive secondary data such as national statistics and other monitoring systems, based on data between 2018 and 2025.

In the case of Ireland, a total of four dairy operators were interviewed (two organic and two agroecological), and data were drawn from national statistics (Central Statistics Office Ireland), EU monitoring systems (Eurostat agricultural databases), and industry reports from Bord Bia and the Irish Farmers' Association. The dairy farmers were selected based on farm type, existing contacts and geographic location, which allowed for more context-rich and detailed interviews to be conducted, while remaining in the scope of the project. Interviews with farmers were conducted following the Food Loss Quantification Manual, using a perceptual approach to gather information (Table 26-PartA, Table 27-PartB, and Table 28-PartC) rather than relying solely on quantitative data. This allowed farmers to describe losses mostly in their own terms, capturing nuances that would not be visible through records alone. The selection of case study farms was purposive, ensuring representation across different scales of operation, geographic regions within Ireland, and production systems. The production systems looked at were organic and agroecological systems, with a comparative study carried out on conventional systems in Belgium.

The methodology used in Belgium was a mixed-methods case study, similar to Ireland. A purposive sample of two farms, representing the conventional system was selected as the case studies. Primary data was gathered on farm through semi-structured interviews with the farmers. To enrich the primary data, secondary quantitative data was be extracted from governmental databases (i.e. Eurostat, Belgian Government etc.), which helped to provide a standardised metric on figures like yield and input quantities. This combination of farmer-centred perspectives with comparable, publicly sourced statistics enables a robust comparative assessment of the three production systems. The typical seasonal, ecologically-minded approach that is used in Ireland is categorised as 'agroecological', combining both organic aspects as well as more consumer driven practices. Some farms are organic, meaning that there is minimal input from humans, such as fertilisers, artificial insemination and machinery for milking and processing. The dairy operations included both large-scale commercial enterprises and smaller family-run operations, reflecting the diversity within Ireland's dairy sector.

8.3.8.3 Measuring and data extrapolation to farm

The following tables outline each of the key parameters to be calculated and their source for measuring food loss in the milk case, using the case of Ireland as explicatory case.

- In the **Pre-Milking stage**, the following formula is used.

$$\frac{(CM + PD + A) \times L}{TC \times AEY}$$

Table 48 and Table 49 below outlines each of the key parameters and their sources.

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Table 48. Key parameters to be calculated in pre-milking stage (Part A)

Parameter	Symbol	Explanation	Irish Source	EU/Regulatory Source
Cow Mortality During Dry Period	CM	Number of dairy cows that die during the dry period (non-lactating interval between lactations). These deaths represent a complete production loss as the animal never enters the next lactation cycle.	CSO Livestock Surveys (annual cattle population and mortality statistics); IFA animal health reports; DAFM (Dept. of Agriculture, Food & the Marine) disease notifications.	Eurostat Farm Structure Survey (FSS) – records livestock numbers across EU-27; EU Animal Disease Notification System (ADNS) under Regulation (EU) 2016/429 (Animal Health Law); EFSA animal health and welfare reports.
Pre-Calving Deaths	PD	Number of cows that die in the period immediately before calving (the transition period). These deaths are often linked to metabolic disorders, injury, or difficult calvings and result in total production loss for that lactation.	CSO Livestock Surveys; DAFM cattle registration database (AIMS – Animal Identification and Movement System); IFA reports on disease and weather-related mortality.	EU Council Regulation (EC) No 1760/2000 on cattle identification and registration; TRACES NT (Trade Control and Expert System) for animal movement; Eurostat agri-environmental indicators.
Abortions / Stillborn	A	Number of pregnancy losses (abortions) and calves born dead (stillbirths) in the herd. Both represent complete losses of the expected lactation from those cows, and indicate reproductive inefficiency in the herd.	DAFM bovine disease surveillance reports; Animal Health Ireland (AHI) BVD (Bovine Viral Diarrhoea) eradication programme data; Irish Cattle Breeding Federation (ICBF) herd records.	EU Animal Health Law (Reg. 2016/429) – notifiable disease reporting; EFSA scientific reports on bovine reproductive diseases; Eurostat livestock statistics.

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Table 49. Key parameters to be calculated in pre-milking stage (Part B)

Low performers of the Average Expected Yield per Cow.	L	The average milk yield per cow expected from cows that are considered lower-performing or at-risk animals within the herd. This parameter weights the production loss by the yield profile of the affected animals rather than assuming a uniform average across the entire herd.	ICBF milk recording data (detailed per-cow yield records); Teagasc National Farm Survey; individual farm milk recording schemes (e.g. ICBF HerdPlus).	ICAR (International Committee for Animal Recording) guidelines on milk recording; EU Reg. 2016/1012 on zootechnical legislation for recording performance of purebred animals; Eurostat agri-structural statistics.
Total cows intended for lactation	TC	The total number of cows in the herd that were expected to enter lactation in a given season. This is the denominator representing the full productive capacity of the herd before any losses occur.	CSO June Livestock Survey; DAFM AIMS cattle database; individual farm records / herd registers (legally required under SI No. 747 of 2014 – Diseases of Animals Act).	Regulation (EC) No 1760/2000 – mandatory bovine identification and registration; Eurostat Farm Structure Survey; EU Dairy Statistics (Eurostat milk collection data).
Average Expected Yield per Cow	AEY	The average milk yield per cow expected across the entire herd under normal, healthy conditions for a given lactation period. It serves as the baseline production benchmark against which losses are scaled.	ICBF national milk recording database; Teagasc Moorepark dairy production benchmarks; Bord Bia Origin Green sustainability reports (herd-level yield data).	Eurostat milk statistics (EU-27 average yields); FAO/OECD agricultural outlook data; ICAR world dairy situation reports; EU Common Agricultural Policy (CAP) farm advisory system data.

- In the **Milking and Transport stage**, the following formula is used.

$$FL\ in\ milking\ and\ transport = \frac{Downgraded\ milk}{Total\ milk\ collected}\ x\ 100$$

Table 50 below outlines each parameter and their sources.

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Table 50. Key parameters to be calculated in milking and transport stage

Parameter	Symbol	Explanation	Irish Source	EU/Regulatory Source
Downgraded Milk	Downgraded Milk	Volume of raw milk collected from farms that fails to meet quality standards and is therefore rejected, downgraded, or diverted away from intended high-value processing (e.g. diverted from liquid milk or cheese to animal feed). Quality failures typically relate to somatic cell count (SCC), total bacterial count (TBC), inhibitory substances (antibiotics), or temperature non-compliance	Bord Bia dairy quality grading records; individual co-op and dairy processor intake reports (e.g. Glanbia, Dairygold, Kerry); Teagasc advisory reports on milk quality; DAFM dairy hygiene inspection results	EU Reg. (EC) No 853/2004 (hygiene of food of animal origin) – sets legal limits for SCC (≤400,000 cells/ml) and TBC (≤100,000 cfu/ml) for raw milk; Reg. (EC) No 854/2004 (official controls on animal products); Eurostat dairy statistics; IDF (International Dairy Federation) quality standards
Total Milk Collected	Total Milk Collected	Total volume of raw milk collected from all farms by dairy processors or co-operatives during a given reference period (typically monthly or annually). This is the gross milk intake figure before any quality deductions or adjustments	CSO Milk Statistics (monthly and annual milk collection returns); Bord Bia dairy market reports; individual dairy processor/co-op collection records (mandatory reporting to DAFM under SI regulations).	Eurostat milk and dairy products statistics (monthly collection data from all EU-27 Member States); EU Market Observatory for Milk (European Commission); Reg. (EU) 2017/1185 on notifications and transmission of information for agricultural markets.

- In the **Post-Milking Stage,** the following formula is used.

$$\frac{MR - EDO}{MR} \; x \; 100$$

Table 51 outlines each parameter and provides sources and regulations for each parameter.

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Table 51. Key parameters to be calculated in post-milking stage

Parameter	Symbol	Explanation	Irish Source	EU/Regulatory Source
Milk received at Plant	MR	Total volume of raw milk that arrives at and is accepted by a dairy processing plant (creamery, cheese factory, liquid milk facility, etc.) during a defined period. This is the gross input of raw milk into the processing system and serves as the denominator for calculating processing-stage losses.	Bord Bia export and processing reports; DAFM dairy processor annual returns; CSO milk statistics; individual plant intake records (e.g. Glanbia, Ornua, Kerry, Dairygold).	Eurostat milk and dairy products statistics; EU Market Observatory for Milk; Reg. (EU) 2017/1185; EU Drinking Milk Regulations and dairy product standards under Reg. (EC) 853/2004 for plant hygiene controls
Edible Dairy Output	EDO	Total volume (or milk equivalent) of all edible dairy products produced at the plant from the milk received. This encompasses all marketable outputs: liquid milk, cheese, butter, yoghurt, cream, milk powder, and other human-food products. It excludes non-food by-products (e.g. whey to animal feed, wastewater), processing waste, and losses during chilling/storage.	Bord Bia dairy export and production statistics; Ornua and co-op production accounts; Teagasc food processing efficiency data; IFA cold-chain and processing loss surveys.	Eurostat dairy products statistics (volumes of butter, cheese, SMP, WMP, etc. at EU level); EU Market Observatory for Milk; IDF world dairy situation; Food Balance Sheets (FAO); Reg. (EU) 2021/2117 (CMO

Table 52 summarises the data collection and data extrapolation methodology for each sub-stage of the milk production process, exemplified with the Irish Case study.

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Table 52. Quantification methodology used to calculate Irish dairy losses across the main sub-stages

Stage	Data Sources	Calculation (example)	Validation (via interviews)
Pre- Milking (Production loss)	• CSO- Livestock surveys • Eurostat-Farm Structure Survey • IFA report on disease/weather impact on grazing	Percentage Loss= (Cow mortality during dry period (CM) plus precalving deaths (PD) plus abortions/stillbirths) (A) multiplied by average expected yield per cow (L) divided by (Total cows intended for lactation (TC) multiplied by Avg. Expected Yield per cow (AEY)) $Percentage\ loss:$ $= \frac{(CM + PD + \mathrm{A})\ x\ L}{TC\ x\ AEY}$	Farmers- discuss disease outbreaks, fertility issues, weather stress
Milking and transport	• CSO slaughter data and carcass weights • Eurostat- meat balance sheets • Bord Bia- grading standards (dairy quality)	Percentage Loss Dairy = (downgraded milk divided by total milk collected) multiplied by 100 $Percentage\ loss:$ $= \frac{Downgraded\ milk}{Total\ milk\ collected}\ x\ 100$	Interviews on carcass rejection. Interviews on milk quality downgrades.
Post-Milking (Processing and Storage)	• Bord Bia- export reports (dairy) • Eurostat- Food balance sheets (processing waste) • IFA- data on spoilage during chilling/transport	Percentage Loss = (Milk Received at Plant (MR) minus Edible Dairy Output (EDO)) divided by Milk Received at Plant multiplied by 100 $Percentage\ loss:$ $= \frac{MR - EDO}{MR}\ x\ 100$	Farmers highlighted cold-chain failures, processing inefficiencies etc.

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8.3.8.4 *Illustrative measurements. Milk case study in Ireland and Flanders*

The following results draw on both the Irish and Flemish dairy case studies, each conducted using the same two-stage methodology: quantitative data from national statistical sources (CSO for Ireland, Statbel for Flanders) was collected first, then validated and supplemented through semi-structured interviews with dairy farmers in each region. Table 10 provides a comprehensive overview and structural comparison of the main food loss categories identified across both case studies. Comparisons are grounded in shared EU Regulatory frameworks (Reg. 852/2004; 853/2004) and official control systems. Where Irish stage level loss percentages remain under-reported in published sources, Flemish values are used as a proxy for direct physical rejection at delivery.

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), caused by:
    - Mastitis treatment withdrawals (65% of disposal volume)
    - Other antibiotic treatments (25% of disposal volume)
    - Preventive medication withdrawals (10% of disposal volume)
- Tank Contamination Events: 2-4 events per farm annually, resulting in 2,000-10,000 litres lost per incident, caused by:
    - Equipment malfunction (40% of events)
    - Power outages affecting cooling (30% of events)
    - Bacterial contamination (30% of events)
- Collection Logistics Failures: 0.5-1% of annual production, primarily due to:
    - Weather-related access issues (60% of logistics losses)
    - Vehicle breakdowns (25% of logistics losses)
    - Scheduling conflicts (15% of logistics losses)

The table highlights distinct but comparable loss profiles across both dairy systems, spanning production and immediate post-milking stages.

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Table 53. Summary table of overview and comparability of the main food loss categories and drivers identified across the dairy sector by substages (calf birth to creamery intake) between Ireland and Flanders case studies (Mean results from 2018-2025) (Part A)

Stage	Loss Category	%Loss Flanders	% Loss Ireland	Magnitude	Sub-Components / Notes (drivers)	Degree of Comparability and Key Difference
Production loss (Biological / Early Life calf-related allocation)	Non-marketed milk	~4% (structural)	~4% (structural)	N/A	Milk allocated to calf feeding rather than sold *Not a "loss" in strict FLW terms; diverted from market*	High Biological norm, not system-specific
Milking losses	Physical spillage / technical loss	0.05–1%	Likely similar range	Low frequency (HIGH impact)	Equipment malfunction and inefficiencies, power outages, tank washout and residues (pharmaceutical or bacterial contamination), illness. *Influenced by technology level & maintenance*	High Technology adoption similar under EU systems
Post-milking food loss (Transport)	Tank contamination and downgrade	0.2–0.5%	Likely similar	Low frequency (HIGH impact)	Export specification failures, tank leakage and contamination during haulage. *Occurs between farm and creamery*	Moderate–High Ireland's greater geographic spread may slightly increase variability

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Table 54. Summary table of overview and comparability of the main food loss categories and drivers identified across the dairy sector by substages (calf birth to creamery intake) between Ireland and Flanders case studies (Mean results from 2018-2025) (Part B)

Post-milking food loss (Rejection at creamery: intake failure)	Regulatory removal	0.05–0.2% (documented <1% total primary loss)	Not formally reported; assumed similar magnitude	N/A	Specification mismatches (fat classification), antibiotic residues, temperature failures, hygiene non-compliance. *Governed by EU hygiene legislation*	Moderate Reporting differences, not necessarily structural differences
Post-milking food loss (Total measurable pre-processing loss excluding calf allocation)	Physical withdrawal	~<1% documented (≈0.95%)	Not formally quantified; likely within similar order of magnitude	High frequency	Combined technical, transport and rejection. *Majority occurs before processing begins*	Moderate Ireland lacks published stage-disaggregated statistics

Although detailed national statistics specifically quantifying food loss in milk at primary production are rare, any available data indicates that milk loss on farm and at the collection level is quite low relative to total milk production in conventional systems. Current secondary data analysed showed that in Flanders, total identifiable milk loss amounted to less than 1% of total milk collected, with contamination (e.g. antibiotic rejections) accounting for an almost negligible amount of loss (~0.04%) out of roughly two billion litres of milk. This ~1% figure is a useful placeholder for typical milk loss in a conventional i.e. intensive dairy system, as Flanders has approximately 2 billion litres of milk deliveries resulting in a roughly 18.9 million litres loss. The losses attributed to contamination or otherwise unusable milk are recorded systematically and are low comparative to total volume produced. This suggests that well-managed dairy chains can minimise the losses in the primary production sector.

In contrast, the same level of data is not reported or recorded in Ireland, as it is typically pertaining to production volumes and market deliveries. Due to its grass-led, agroecological model, production varies year on year (e.g. structural changes in herd size and weather impacts) and so demonstrating the highly reactive and sensitive nature of its dairy sector and how climatic and seasonal variability can impact an agroecological/organic system and their output. As a result of this, there are many indirect losses (i.e. price-driven overproduction, quality downgrades, capacity constraints during peak months, reduced production during adverse weather) that are not captured as explicit milk loss in supply balances or in any national statistics. The lack of systemic loss reporting means that this

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may currently be understated, as only direct farm rejections are measured/considered, and all other data must be collected on a farm-to-farm basis (i.e. from the interviews conducted).

Milk at the farm delivery point generally has very low physical loss before processing in both countries/systems. Documented loss percentages in Flanders (<1%) provide a useful benchmark for Irish estimates. Using Flanders as a comparative proxy is justified, as both regions operate withing the same EU regulations. The comparison is limited specifically to milk rejected at collection or delivery due to contamination or quality issues, where both regions operate under harmonised EU hygiene legislation and official control systems. Within this narrow regulatory domain, similar institutional and legal structures make comparable rejection rates plausible.

However, this proxy does not imply structural equivalence between the two dairy systems. While the production systems differ, these differences influence mainly processing effectiveness, output variations and potential losses rather than the small fraction of milk withdrawn at delivery. The reliance on proxy data therefore reflects not assumed similarity, but rather the absence of systemically reported Irish primary-stage loss data. This gap underscores a broader limitation in official statistics and reinforces the necessity for harmonised, stage-specific reporting standards to enable cross-country comparison.

8.3.8.5 Measuring costs

Data collection and analysis required a three-person team: a primary investigator, a secondary investigator and a post-graduate student. Over the course of the fieldwork, we devoted approximately 62 hours in total to the interview process, including scheduling, travel, conducting the semi-structured interviews, and recording the responses. Subsequent transcription and integration of the interview data with registry information were carried out by the post-graduate student, with oversight and validation checks performed by the primary and secondary investigators.

8.3.8.6 Adaption to other food commodities

The methodology developed for Irish dairy systems demonstrates some transferability potential to other animal-source food commodities, with appropriate sectoral calibrations. The RH model's focus on physiological and economic readiness provides a robust foundation for adaptation across diverse protein production systems.

Examples of such are other milk producing animals, such as goats and sheep.

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8.4 Example of food loss measurements in fruit and vegetables case study

It is important to note that in the fields covered by "FL estimated (using median)," several figures may be preceded by a parenthesis and a percentage. This indicates the estimates based on whether the sampling covers 0.1%, 1%, and/or 10% of the plot. For example, in the case of measuring food loss of organic lettuces (date: 27/03/2024), if extrapolated to the entire plot, which covers a total area of 1,000m^2, a 0.1% sample results in a loss of lettuces for the plot amounting to 9,500 kilograms, translating to an index of 95,000 kilograms per hectare. However, if a total sampling of 1% is used, the estimated loss for the entire plot drops to 300 kilograms (3,000 kilograms per hectare), and if a 10% sampling is taken, the estimates are 127.5 kilograms (1,275 kilograms per hectare).

Table 55. Example of food loss measurements in fruit and vegetable case study (Part A). Agro (Agroecological); Org (Organic); Conv (Conventional) production systems

Crop	NACE Code	CPA Code 6 digits	Production system	Date	Measurements			Samples applied			FL estimated (using median)		Main reason(s)
					Pre-harvest	Inter-harvest (cuts)	Post-harvest	0.10 %	1 %	10 %	Kg per plot	Kg per ha	
Tomatoes	01.13 Growing of vegetables and melons, roots and tubers	01.13.34 Tomatoes	Agro	05/07/2024		X				X	57 kg (300 m^2)	1,155	Plagues/diseases
Tomatoes	01.13 Growing of vegetables and melons, roots and tubers	01.13.34 Tomatoes	Conv	03/07/2024	X					X	16.8 kg (2700 m^2)	62.2	Blossom-end rot and aesthetic damages
Cabbages	01.13 Growing of vegetables and melons, roots and tubers	01.13.12 Cabbages	Conv	03/07/2024	X					X	0 kg (100 m^2)	0	(-)
Lettuces	01.13 Growing of vegetables and melons, roots and tubers	01.13.14 Lettuce	Conv	04/06/2024			X	X	X	X	(0.1%) 150 kg (1%) 120 kg (10%) 86 kg (350 m^2)	(0.1%) 4285.71 (1%) 3428.57 (10%) 2457.14	Aesthetic damages, plagues/diseases and management/overlapping of crops
Pears	01.24 Growing of pome fruits and stone fruits	01.24.21 Pears	Conv	04/07/2024	X					X	33.25 kg 0.1 kg per tree (350 trees) (0.56 ha)	64.86	Plagues/diseases

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Table 56. Example of food loss measurements in fruit and vegetable case study (Part B). Agro (Agroecological); Org (Organic); Conv (Conventional) production systems.

Crop	NACE Code	CPA Code 6 digits	Production system	Date	Measurements			Samples applied			FL estimated (using median)		Main reason(s)
					Pre-harvest	Inter-harvest (cuts)	Post-harvest	0.10 %	1 %	10 %	Kg per plot	Kg per ha	
Pears	01.24 Growing of pome fruits and stone fruits	01.24.21 Pears	Conv	15/07/2024			X			X	21 kg 0.06 kg per tree (350 trees) (0.56 ha)	40.97	Plagues/diseases
Plums	01.24 Growing of pome fruits and stone fruits	01.24.27 Plums	Org	07/06/2024		X				X	92.3 kg 7.1 kg per tree (13 trees) (376 m^2)	2,454.79	Plagues/diseases
Plums	01.24 Growing of pome fruits and stone fruits	01.24.27 Plums	Org	07/06/2024			X			X	52 kg 4 kg per tree (13 trees) (376 m^2)	1,382.98	Plagues/diseases and eaten by bird
Lettuces	01.13 Growing of vegetables and melons, roots and tubers	01.13.14 Lettuce	Org	27/03/2024			X	X	X	X	(0.1%) 9,500 kg (1%) 300 kg (10%) 127.5 kg (1,000 m^2)	(0.1%) 95,000 (1%) 3,000 (10%) 1,275	
Oranges	01.23 Growing of citrus fruits	01.23.13 Oranges	Org	19/06/2024			X			X	520 kg 0.65 kg per tree (800 trees) (1.76 ha)	294.92	Difficulties in identifying commercial outlets and plagues/diseases
Peaches	01.24 Growing of pome fruits and stone fruits	01.24.25 Peaches	Conv	17/06/2024			X		X	X	(1%) 174 kg 2 kg per tree (10%) 200.39 kg 2.3 kg per tree (87 trees) (0.295ha)	(1%) 589.43 (10%) 678.83	Aesthetic reasons (undersized, wonky or slightly imperfect fruits)

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Table 57. Example of food loss measurements in fruit and vegetable case study (Part C). Agro (Agroecological); Org (Organic); Conv (Conventional) production systems.

Crop	NACE Code	CPA Code 6 digits	Production system	Date	Measurements			Samples applied			FL estimated (using median)		Main reason(s)
					Pre-harvest	Inter-harvest (cuts)	Post-harvest	0.10 %	1 %	10 %	Kg per plot	Kg per ha	
Oranges	01.23 Growing of citrus fruits	01.23.13 Oranges	Conv	02/11/2023	X				X		14,415 kg 3.1 per tree (4,650 trees) (12 ha)	1,201.25	Fallen to the ground but not collected/harvested and plagues/diseases
Oranges	01.23 Growing of citrus fruits	01.23.13 Oranges	Conv	07/11/2023			X		X		12,881 kg 2.77 per tree (4650 trees) (12 ha)	1,073.42	Fallen to the ground but not collected/harvested and plagues/diseases
Oranges	01.23 Growing of citrus fruits	01.23.13 Oranges	Conv	09/11/2023	X				X		7,980 kg 2.04 kg per tree (3912 trees) (8 ha)	997.5	Fallen to the ground but not collected/harvested and plagues/diseases
Oranges	01.23 Growing of citrus fruits	01.23.13 Oranges	Conv	20/12/2023			X		X		17,526 kg 4.48 kg per tree (3912 trees) (8 ha)	2,190.75	Fallen to the ground but not collected/harvested and plagues/diseases
Tangerines	01.23 Growing of citrus fruits	01.23.14 Tangerines, mandarins, clementines	Conv	10/11/2023	X				X		2,201 kg 1.37 kg per tree (1600 trees)		Aesthetic reasons (undersized) and lack of utilisation for other purposes (juices). Furthermore, plagues/diseases.
Tangerines	01.23 Growing of citrus fruits	01.23.14 Tangerines, mandarins, clementines	Conv	15/11/2023			X		X		0 kg 0 kg per tree (1,600 trees)	0	(-)

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Table 58. Example of food loss measurements in fruit and vegetable case study (Part D). Agro (Agroecological); Org (Organic); Conv (Conventional) production systems

Crop	NACE Code	CPA Code 6 digits	Production system	Date	Measurements			Samples applied			FL estimated (using median)		Main reason(s)
					Pre-harvest	Inter-harvest (cuts)	Post-harvest	0.10 %	1 %	10 %	Kg per plot	Kg per ha	
Tangerines	01.23 Growing of citrus fruits	01.23.14 Tangerines, mandarins, clementines	Conv	10/11/2023	X				X		1,301 kg 0.54 kg per tree (2400 trees) (34.67 ha)	375.18	Aesthetic reasons (undersized) and lack of utilisation for other purposes (juices). Furthermore, plagues/diseases.
Tangerines	01.23 Growing of citrus fruits	01.23.14 Tangerines, mandarins, clementines	Conv	15/11/2023 and 18/11/2023			X		X		24,000 kg 10 kg per tree 2400 trees) (34.67 ha)	6,633	Aesthetic reasons (undersized) and lack of utilisation for other purposes (juices). Furthermore, plagues/diseases.
Tangerines	01.23 Growing of citrus fruits	01.23.14 Tangerines, mandarins, clementines	Conv	08/11/2023	X				X		822 kg 0.27 kg per tree (3000 trees) (29.42 ha)	282.1	Aesthetic reasons (undersized) and lack of utilisation for other purposes (juices). Furthermore, plagues/diseases.
Tangerines	01.23 Growing of citrus fruits	01.23.14 Tangerines, mandarins, clementines	Conv	24/01/2024			X		X		2,145 kg 0.71 kg per tree (3000 trees) (29.42 ha)	736.1	Aesthetic reasons (undersized) and lack of utilisation for other purposes (juices). Furthermore, plagues/diseases.

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