Nitrogen Use Efficiency (NUE)

Guidance Document
for assessing NUE at farm level

Prepared by the EU Nitrogen Expert Panel

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About EU Nitrogen Expert Panel

Key persons from science, policy, industry and agriculture practice in Europe have been invited by Fertilizers Europe to establish the EU Nitrogen Expert Panel. The general objective of the Expert Panel is to contribute to improving NUE in food systems in Europe, through (i) communicating a vision and strategies on how to improve Nitrogen Use Efficiency in agriculture and food systems in Europe; (ii) generating new ideas, and recommending effective proposals and solutions; and by (iii) acting as referee in controversial issues, and (iv) by communicating with authority about nitrogen issues.

The Panel gathered for the first time in Windsor, United Kingdom on 15-16 September 2014, and agreed on a definition of NUE as indicator for agricultural production. This Guidance Document for assessing NUE at farm level was discussed at the 4th meeting of the Panel, in Frankfurt, 8-9 June 2016, and approved at the 5th meeting of the Panel, in Madrid, 24-25 June 2016.

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Executive Summary

Nitrogen (N) is essential for life and a main nutrient element. It is needed in relatively large quantities for the production of food, feed and fibre. It is an essential element of chlorophyll in plants and of amino acids (protein) and nucleic acids in plants, animals and humans. However, excess N pollution is a threat to our health and the environment.

The ambition of the EU Nitrogen Expert Panel is to contribute to improving efficient nitrogen use in food production. Recently, they proposed an easy-to-use indicator for 'nitrogen use efficiency' (NUE), applicable to agricultural land, farms and whole food production–consumption systems. The indicator is based on the mass balance principle, i.e. using N input and N output data for its calculation: NUE = N output / N input. NUE values have to be interpreted in relation to productivity (N output) and N surplus (i.e., the difference between N input and harvested N output). The NUE indicator is easily presented via an input – output diagram. This allows the visualization of NUE, N output and N surplus in a coherent manner, together with possible reference or target values (Figure ES1).

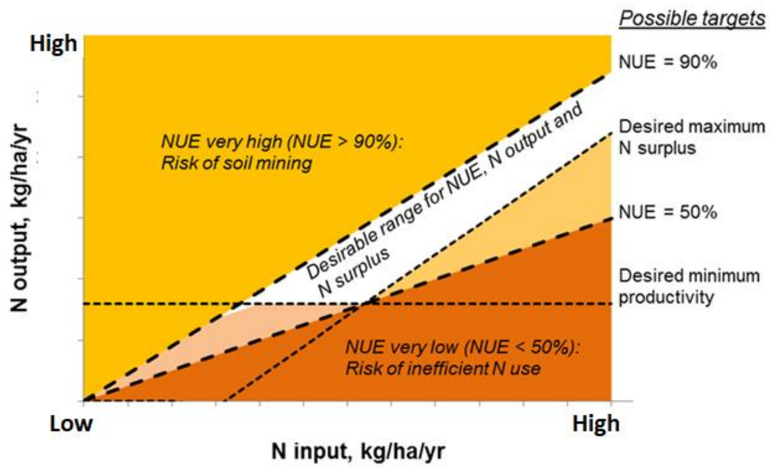

Figure ES1. Framework of the Nitrogen Use Efficiency (NUE) indicator. ***The numbers shown are illustrative of an example system and will vary according to context (soil, climate, crop, farming system).*** *The area within the diagonal wedge represents a range of desired NUE between 50% and 90%: lower values exacerbate N pollution and higher values risk mining of soil N stocks by soil carbon depletion. The horizontal line indicates a desired minimum level of productivity for cropping system. The additional diagonal (short dashes) represents a limit related to maximum N surplus to avoid substantial pollution by N losses. The combined criteria serve to identify the most desirable range of outcomes (area in white).*

The purpose of this Guidance Document is to describe the procedures and data needed for users interested in the estimation and assessment of NUE, N output and N surplus at the farm level. For estimating NUE and communicating the results, data and information are required about (i) the total N inputs into the farm and the N output in products exported from the farm, (ii) the characteristics of the system (e.g. farm, crop system, livestock housing system,) and its boundaries, (iii) the time span of the analyses, and (iv) possible changes in the stock of N in the system.

1. Introduction

Nitrogen (N) is essential for life and plays a key role in food production. Nitrogen is the most important crop-yield limiting factor in the world, together with water (Mueller et al., 2012). That is why farmers apply animal manures, compost and mineral N fertilizers to cropland. They grow also N fixing crops, such as beans, peas, and clover, and/or N-fixing trees in agroforestry systems.

With increasing N input, there is an increase in the risk of surplus N application and losses to groundwater, surface water and the atmosphere, which are harmful to biodiversity, the functioning of ecosystems and potentially to human health. Further, N may accumulate in leafy crops and soils to toxic levels. The management of N is therefore important, also because synthetically fixed N is costly. Nitrogen management aims at achieving agronomic objectives (farm income, high crop and animal productivity) and environmental objectives (minimal N losses) simultaneously. However, N management is not easy, because the N cycle is complex and N is easily lost from the farm to the environment.

Indicators can play a key role in directing management decisions. Nitrogen use efficiency (NUE) can be considered a key indicator in agriculture, but currently there is no uniform and robust methodology and protocol for its estimation and use. The benefits of using NUE as an indicator are shown in EUNEP 2015. The EU Nitrogen Expert Panel recently proposed an easy-to-use indicator for 'nitrogen use efficiency' (NUE), applicable to agricultural land, farms and whole food production–consumption systems (EU Nitrogen Expert Panel, 2015). The indicator is based on the mass balance principle, i.e. using N input and N output data for its calculation: NUE = N output / N input. NUE values have to be interpreted in relation to productivity (N output) and N surplus (i.e., the difference between N input and N output).

The purpose of this Guidance Document is to describe the procedures and data needed for users interested in the estimation and assessment of NUE, N output and N surplus at the farm level. A farm is the basic management unit for optimizing resource use efficiency, including N. This holds for cropping systems (crop rotations) as well as mixed crop-animal production systems and specialized animal production systems. That is why the farm level is the primary unit for estimating NUE in agriculture. Field-level estimates of NUE may be equally useful, especially when the interest is in specific crops, but such partial analyses run the risk of a possible underestimation or overestimation of NUE, because of the neglect of crop rotation effects.

For estimating NUE at farm level and communicating the results, data and information are required about (i) the characteristics of the farm (type of farm, crop rotation system, permanent cropping systems, livestock farm) and its boundaries, (ii) the total N inputs into the farm and the N output in harvested products out of the farm, (iii) the time span of the analyses, and (iv) possible changes in the stock of N (soil, feed, manure, fertilizers, animals) in the farm. This document provides the technical information for that. It allows users (farmers, extension services, accountants, industry) to estimate NUE, N output and N surplus in a uniform manner. The results will help farmers also to compare their N use performance with those of other farmers, and to identify possible management options for improvement.

Several studies have made estimates of NUE at farm level. Notable examples are the studies by Öborn et al (2003), Schröder et al (2003), Powell et al (2010), Aarts et al (2013) and Dalgaard et al (2012). However, there is no common, approved protocol and guidance document for a uniform estimation of NUE at the farm level. Often different procedures are used, which makes comparisons between farms difficult. Aarts et al (2013) provide a practical manual to assess and improve dairy farm performances, including N use efficiency, for dairy farms in NW Europe. Bittman et al (2014) made a general outline for estimating farm N balances and NUE at farm level for basically all types in UN-ECE countries, but a practical Guidance Document has not been provided yet. Further, OECD/EUROSTAT have made a guidance document for estimating N balances of the agricultural sector at national level, and EPNB-TFRN (2012) published a guidance document for estimating National Nitrogen Budgets for all main sectors of societies.

This Guidance Document for estimating and assessing NUE at farm level builds on the aforementioned reports about farm N balances. It is meant for practical use and has been tested in practice in a number of EU member states. During the next few years may be further updated.

2. How is Nitrogen Use Efficiency (NUE) defined and calculated?

Farm NUE is defined as the ratio of total N input and total N output in products of a farm:

$$NUE = [\Sigma(N\ output) / \Sigma(N\ input)] * 100 \qquad \text{Equ. 1}$$

NUE = nitrogen use efficiency (%)
N output = N in produce exported from farm (kg N / farmed area (ha)) (kg N/ha/yr)
N input = N in operating resources and feed (kg N / farmed area (ha)) (kg N/ha/yr)

Hence, NUE is the ratio of N output and N input, NUE increases as the N output in products increases and/or the N input decreases. Conversely, NUE is low when the N output in products is relatively low and the N input relatively high.

Many input-output combinations are possible, but the ideal case is a high N output via products combined with a high NUE and a low N surplus (difference between N input and N output, Equ. 4). Reporting NUE alone is not sufficient as at very high N levels even with high NUE high N surpluses can occur. Therefore, for proper interpretation, NUE should be reported together with the N surplus (as proxy for the N loss to the environment). In addition, the N output (Equ. 2) in products as indicator for the productivity and land use efficiency of the farm is an important ancillary variable for interpretation of NUE values. Reporting N surplus and farm productivity alone is also not sufficient, as their combination cannot reflect the risk of loss of soil fertility, i.e. soil mining. Therefore, the combination of NUE, N surplus and N-output defines the range of well-organized farm N management (Fig. 1).

The **N output** (crop and animal products) per unit area is estimated from the total amount of products and the N content of the products exported from the farm in a production year(s) divided by the farmed area.

N output (kg N/ha/yr) = (Σ (mass of products (kg) x N concentration in products (kg N/kg product))/farmed area (ha)/yr Equ. 2

Likewise the **N-input** per unit area is calculated from the total amount of inputs and their N content in a production year(s) divided by the farmed area:

N input (kg N/ha/yr) = (Σ (mass of input (kg) x N concentration in input (kg N/kg input))/ farmed area (ha)/yr Equ. 3

For crop production systems, the N output in harvested crop removed from the land is considered, including fruits, vegetables, and straw (in case the straw or other crop residues are transported off from the farm). For animal production systems, the N output may be milk, meat, egg, wool and animals. For mixed production systems, both crop and livestock products transported off the farm are included. Inputs include purchased fertilizers, composts, feed, planting materials, and bedding material, but also atmospheric deposition and biological N fixation by legumes. The mass of products and inputs is known from the yield statistics or from sales invoices of the farm, the N concentration in the harvested products and purchased products can be found from analyses (preferably) or from look-up tables (see chapter 3) or from a combination of farm statistics and look-up tables, using a tiered approach. Farm area should be known by each farm owner.

Farm N surplus per unit area (kg N/ha/a) is calculated as the difference between total N inputs and N outputs per unit area:

N surplus (kg N/ha) = Σ(N input) - Σ(N output) Equ. 4

Care should be taken collecting information about possible changes in N stocks in the farm, in temporarily stored products on the farm in (i.e. cereals, silage,…), fertilizers, manure and animals.

Possible changes in the soil N stock should also be considered, because they can be considerable following changes in crop rotation (although these changes are not easily accurately quantified).

NUE is influenced by the length of the period under consideration. For an arable farm, ideally a whole crop rotation should be considered. For animal production systems, ideally the whole lifetime of an animal needs to be considered. If the crop rotation does not change much and the herd also does not change much, accurate estimates can be made over one-year periods. Preferably, records of N input, N output, NUE and N surplus should be made over a number of years, to trace annual variations, and to trace changes in performance over time.

NUE is easily presented via an input – output diagram. This allows the presentation of NUE, N output and N surplus in one graph, together with possible reference or target values (Figure 1).

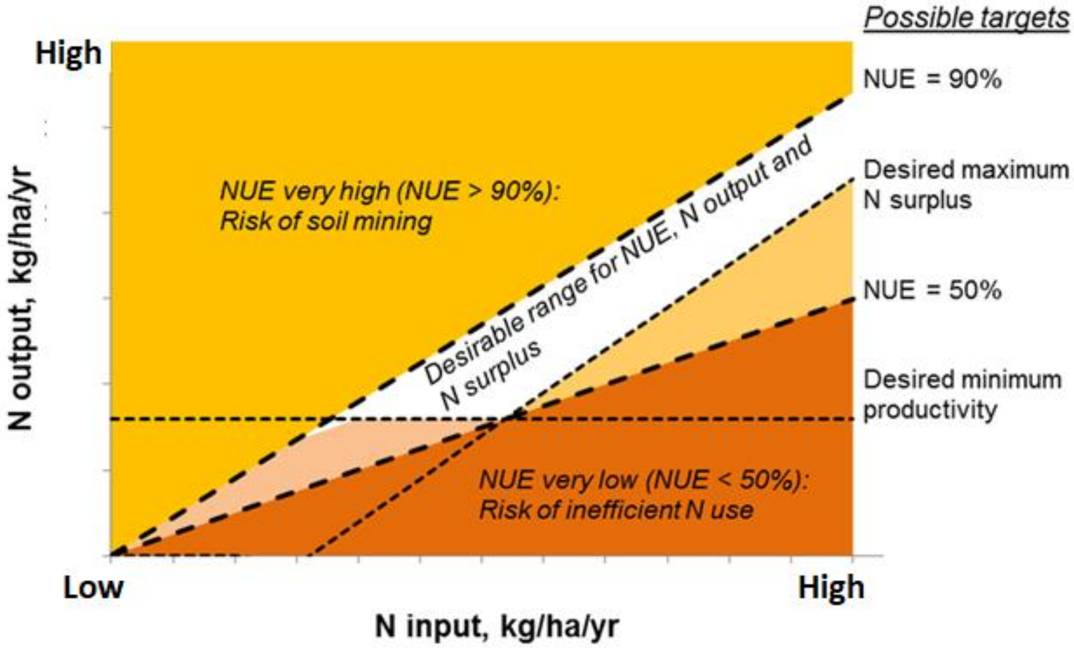

Figure 1. Framework of the Nitrogen Use Efficiency (NUE) indicator. ***The numbers shown are illustrative of an example system and will vary according to context (soil, climate, farming system).*** *The area within the diagonal wedge represents a range of desired NUE between 50% and 90%: lower values exacerbate N pollution and higher values risk mining of soil N stocks by soil carbon depletion. The horizontal line indicates a desired minimum level of productivity for cropping system. The additional diagonal (short dashes) represents a limit related to maximum N surplus to avoid substantial pollution by N losses. The combined criteria serve to identify the most desirable range of outcomes (area in white).*

A graphical presentation of N input and N output allows the performance to be assessed in relation to NUE and N surplus simultaneously. It also allows changes over time in NUE to be shown, as well as N output, N input and N surplus. Moreover, it allows the deviation of an observed situation from possible NUE target or reference values to be indicated.

Figure 1 shows three zones for NUE, namely a zone with low NUE values, a zone with a 'desired' range of NUE values, and a zone with high NUE values. The rational of three zones is that both a 'too high' and 'too low' NUE are undesirable, especially over long time periods. A 'too low' NUE value indicates inefficient resource use and points to high environmental N losses; a 'too high' NUE points to resource depletion, i.e., soil N depletion. For some period, mining of nutrients from highly fertile soils may be considered a good practice, as it results in a high resource use and it may decrease potential nutrient losses.

While good management can reduce losses, in practice some N losses are inevitable due to continuously ongoing N transformation processes in soil (e.g. denitrification) or N leaching with excess water. In the case of the example in Figure 1 for cropping systems, we therefore show an upper limit target value for NUE of 90%. The lower limit target value for NUE is here shown at 50%, being a value that has been shown to be easily achievable for most current cropping systems, but may be difficult to achieve in livestock systems. Thus, there is a need for targets to be established for different agricultural systems, regions and soil types.

Figure 1 shows also possible target or reference values for N output and N surplus. The rational for a reference value for N output is that some minimum yield level should be achieved, given the need to produce a desired amount of food, and for farmers to be competitive by sufficient production which should be acknowledged by environmental and farming regulations. In addition it indicates land use efficiency in a world generally limited in arable land. The target N output will depend in farms type and management as well as in regions and countries. For example arable systems including crops non dedicated to protein production in the rotation might have lower targets than those fully dedicated to protein production. Once again, high target values might be difficult to achieve for animal production systems.

The rationale for a target value for N surplus is that N surplus is a driver and rough estimate for N losses to the environment. Specific surplus values in regulations shall help that thresholds for nitrate-N and total N in groundwater and surface water bodies are not surpassed. Further, N losses via ammonia (NH_3) volatilization, denitrification and nitrous oxide (N_2O) emissions to air have to be minimized. There is no target for a minimum N surplus, but very low values for N surplus (< 0 kg ha^{-1} yr^{-1}) are associated with a NUE value of >90%, and hence are not recommended in the long term. As with the target NUE range and the target N output, the exact target values for N surplus depend on farming systems, regions and soil types.

3. Input and N output variables for different farming systems

Accurate N input and N output data are needed for the estimation of NUE. These data have to be collected, processed and reported in a uniform way, to allow comparison between farms and between years, and to relate results to reference (benchmark) values.

The N inputs and N outputs depend in part on the type of N balance. Here, we propose the farm N balance, mainly because of its ease of data collection; there is no need for estimating the amounts of N in farm-produced grass, fodder and manure production but would be necessary for feed and manure imported and exported from farms.

Table 1 presents the input and output items needed for the farm N balance. These data allow N output, NUE and N surplus to be estimated at farm level, for basically all farm types. Input and output items have to be reported only once on the balance. In the case that animals are imported to the farm and other animals are exported, only the net results should be presented, i.e., on the right-hand side of the balance[1]. Similarly, in the case that animal manure is imported to the farm and other manure exported, only the net manure N input should be reported as input (Table 1). Hence, manure is seen as an input (and not as a harvested output). Likewise, N imported in feed and fodder is reported as a net input value (difference between N imported and exported). Reporting the inputs and outputs on the proper side of the balance is important, as it allows a better comparison between farms.

Table 1. General input and output items considered for the farm N balance.

Nitrogen input items		Nitrogen output items	
Mineral fertilizers	I1	Crop products	O1
Feed and fodder (net)	I2	Animals (net)	O2
Biological nitrogen fixation	I3	Animal products (milk, egg, wool)	O3
Atmospheric N deposition	I4	Trees, branches in orchards (net)	O4
Compost and sewage sludge	I5		
Seed and planting material	I6		
Bedding material (straw, saw dust)	I7		
Animal manure (net)	I8		
Irrigation water	I9		

3.1. Estimation of N inputs

The N inputs have to be estimated from the amounts of products that have been used in a particular year and the mean N content of that particular product. Hence, imported items have to be corrected for changes in stocks at the farmyard.

[1] Evidently, the calculation should be made animal-specific, using animal-specific N content

The amount of N fertilizers used follows from purchase statistics (accounting data) and from possible changes in the stock of N fertilizers on the farm. Each N fertilizer type has its specific N content, which can be derived from the purchase order and/or from the information on the fertilizer bag.

The amount of N in imported feed and fodder used in a particular year also follows from purchase statistics and from possible changes in the stock of the feed and fodder on the farm. The feed and fodder have their specific protein (N) contents, which can be derived from the purchase orders and/or from the information on the feed concentrate bags, and/or from look-up tables presented in the Annex 2. A tier- approach is proposed (see Annex 3), as follows:
Tier 1: General lookup table values, if no national data are available (provided with this guidance document)
Tier 2: Local/national and validated lookup table values in accessible reports
Tier 3: Local product N analyses

The amount of N entering the farm via biological N fixation mainly depends on the type and area of the crops grown on the farm. Beans, peas, lupines, alfalfa and clovers are legumes (Leguminosae) and able to fix atmospheric N_2 in amounts that may range from less than 50 to more than 200 kg of N per ha per yr, depending also on soil type, climate and management. Also here, a tier- approach is proposed (see Annex 4), as follows:
Tier 1: General lookup table values, if no national data are available (provided with this guidance document)
Tier 2: Local/national and validated lookup table values in accessible reports
Tier 3: Measurements of N_2 fixation

The atmospheric N deposition depends on region. It may range from <10 kg to more than 20 kg N ha^{-1} yr^{-1}). Approximate N deposition values can be derived from the website of EMEP (http://webdab.emep.int/Unified_Model_Results/userguide_frame.html). See also Annex 2 for a map with mean N deposition values for the period 2012-2014.

The amounts of compost and sewage sludge used in a particular year follows from purchase statistics and from possible changes in the stock of compost and sludge on the farm. The composts and sludges have their specific N contents, which can be derived from the purchase orders and/or from the information on the bags, and/or from look-up tables presented in the Annex 1, As.

The amounts of seed and planting material used in a particular year follows from purchase statistics and from possible changes in the stock of seed and planting material on the farm. The seeds and planting material have their specific N contents, which can be derived from the purchase orders and/or from the information on the bags, and/or from look-up tables presented in the Annex 1.

The amounts of bedding material (straw, saw dust) used in a particular year follows from purchase statistics and from possible changes in the stock of bedding material on the farm. Bedding materials have a specific N content, which can be derived from the purchase orders and/or from the information on the bags, and/or from look-up tables presented in the Annex 1.

The amounts of imported manure used in a particular year follows from purchase statistics and from possible changes in the stock of imported manure on the farm. Manure types have specific N contents, which can be derived from the purchase orders, and/or from look-up tables presented in the Annex 1.

In irrigated cropping systems, the N input via irrigation water should be reported. It is calculated by multiplying the volume of irrigation applied times the nitrate-N concentration of the water. The volume of irrigation may be recorded or estimated for a crop in a specific location. The nitrate-N concentration of irrigation water depends on its origin (surface, aquifer) and should be obtained for each location.

3.2. Estimation of N outputs

The N outputs have to be estimated from the amounts of products that have been harvested and the mean N content of the particular products. Harvested crops may be stored temporarily on the farm and sold in another year (when prices are expected to be higher). However, the total amount of harvested yield should be recorded, irrespective if the produced is sold in the year of harvest or in a later year. Hence, N outputs are not corrected for storage and changes in stocks (unlike N inputs).

The amount of N in harvested crop products in a particular year follows from yield records (or selling statistics). Each crop product has its specific N content, which can be derived from specific analyses or from look-up tables presented in the Annex 1. Crop residues (e.g. cereal straw, sugar beet leaves, pruning from trees) are included only when the harvested crop residues are exported from the farm.

The amount of N in sold animals in a particular year follows from selling statistics (number of animals and the specific weight of the animals). Each animal type has its specific N content, which can be derived from look-up tables presented in the Annex 1.

The amount of N in sold animal products (milk, egg, wool) in a particular year follows from selling statistics (weight and quality of milk, egg and wool). Each product has its specific N content, which can be derived from look-up tables presented in the Annex 1.

3.3. Approximations of N inputs and outputs

It might be possible that not all N input and output items have been recorded in particular case-studies, or that some items cannot be easily estimated. In that case approximations may have to be made. We propose that always estimates are made for the 9 input items and the 4 output items. The origin of estimates (literature or expert opinion) must be reported.

3.4. Estimating changes in soil N stock

Soil is a main storage of N, especially the top soil (plough layer). A small percentage of the total amount of N in soil (2000 to 10000 kg N ha^{-1}) is in the form of ammonium and nitrate and directly available to plants. Most of the N is stored in soil organic matter and not directly available to plants. Annually about

2% of the organically bound soil N is mineralized and then becomes available to the plants. This N is not free of charge, as the soil organic N store is depleted. Hence, the soil organic N store should be replenished, through the supply of stubble and roots, crop residues, and animal manure.

Changes in soil organic N are common following changes in crop rotation and especially following the conversion of permanent grassland to arable land and vice versa. Changes are also common following changes in manure application and fertilization, changes in soil cultivation practices, and changes in weather conditions (mean temperature, rainfall). These changes can have a large effect on NUE, N output and N surplus.

However, measuring changes in soil organic N content is not easy, as the spatial and depth variations in soil N content are high. Measuring changes in soil organic N content accurately therefore require special sampling and analyses protocols, which will have to be applied uniformly over a sufficiently large period (at least one whole crop rotation or four years).

We recommend that reports about NUE at farm level include a discussion about the possibilities and risks of changes in soil organic N, and about the possible effects on NUE. References should be made to regional/national monitoring studies on changes in soil C and N stocks.

4. Characterization of farm types, management, climate and soil conditions

The NUE depends on the farm type or farming system, management, environmental conditions and socio-economic conditions. Hence, it is important to consider these factors when comparing differences in NUE and when guidelines are formulating for enhancing NUE. This chapter describes the factors that have to be reported in addition to the N input and N output variables described in Chapter 3. This information is needed also to establish (statistical) relationships between NUE and farm type, NUE and management, NUE and climate, and NUE and soil types.

4.1. Characterization of farm types

There is a huge variation in farming systems, in their resource basis, enterprise pattern, crops, animals, and constraints. A first distinction is commonly made between (i) specialized crop production systems, (ii) specialized animal production systems, and (iii) mixed production systems. Eurostat (2015a) distinguishes 8 main farm types (Table 2)[2] and three main classes of land use. About 60% of the utilized agricultural area in the EU-28 in 2013 was classified as arable land, 34% as grassland and 6% as permanent cropland (orchards, vineyards). The total utilized agricultural area in EU28 was 174 million ha in 2013.

Table 2. Agricultural holdings by farm type in EU-28 in 2013 (Eurostat, 2015a).

Code	Farm type	Number of holdings in EU-28 (millions)	Number of holdings in EU-28 (%)
1	Specialist field crops	3.20	29.6
2	Specialist horticulture	0.21	1.9
3	Specialist permanent crops	1.89	17.4
4	Specialist grazing livestock	1.86	17.1
5	Specialist granivores[1]	1.02	9.4
6	Mixed livestock	0.48	4.4
6	Mixed cropping	0.52	4.8
7	Mix crop-livestock[2]	1.50	13.8
8	Other	0.16	1.5
	Total	**10.84**	**100.0**

[1] Granivorous literally means 'feeding on grains and seeds'. In practices it means farms with monogastric animals, mainly pigs and poultry, where often a significant fraction of the feed is imported.
[2] Mixed crop-livestock holding have neither livestock nor crop production as dominant activity; an activity is called dominant if it provides at least two-thirds of the production of an agricultural holding.

[2] There were 10.84 million holdings in EU-28 in 2013. A total of 1.6% had no land, 43% had <2 ha, 33% had 2-10 ha, 15% had 10-50 ha, 3.6% had 50-100 ha and 3.1% had >100 ha. The number of small farms is decreasing over time.

Andersen et al. (2007) developed a farm typology for EU agriculture on the basis of:

- Specialisation: Measured as the output value from the main activity; 10 farm specialization types.
- Size: Measured as the economic size of the farm; 4 classes: <40k€; 40-200k€; 200-1000k€;>1000€ SO[3]
- Intensity: Measured as the total output in Euro per ha; 3 classes: <500; 500-3000; >3000 euro/ha
- Land use: Measured as the proportion of the agricultural area covered by specific types of crops; 9 different land use types were distinguished.

The farm typology of Andersen (2007) is a useful framework for characterizing farm types, as farm size, intensity, specialization and land use are important determinants for NUE, N output and N surplus. The farm typology does however not address the level of externalization of feed use in animal production farms in sufficient detail. Landless animal farms (granivorous) are distinguished (see also Table 2), but a large fraction of land-based animal farms do purchase animal feed from elsewhere, which affects NUE, N output and N surplus of the farm. We therefore propose to include the level of externalization in the farm characterization, where externalization is defined as the percentage of the feed (in dry weight) used on the farm that is imported from elsewhere. In short, farms should be characterized on the basis of the five items listed in Table 3.

Table 3. Proposal for characterization of farms in EU-28.

Nr	Characteristics	Unit of characterisation
1	Specialisation	Specialization type, and output derived from the main activity, in %; The 10 farm specialization types are: 1. arable farms, 2. horticultural farms, 3. permanent crops, 4. dairy farms, 5. beef farms, 6. pig farms, 7. poultry farms, 8. sheep and goat, 9. mixed livestock, 10. mixed farms (all other farms)
2	Land use	Crop rotation and crop types, in %
3	Size	Value of output, European Standard Output (SO) and utilized agriculture area (UAA), in ha
4	Intensity	Value of output (SO), in Euro per ha
5	Externalization	Purchased feed, in % of total feed

[3] SO is the Standard Output, and in Europe is calculated as the average monetary value of the agricultural outputs (crop or livestock) at farm-gate price. It does not take into account the input costs (investment) or the direct payments via subsidies.

4.2. Characterization of Management

Management is often considered to be the fourth production factor, next to land, labour and capital. Sometimes, it is considered the most important factor for the performance of the farm. Management is usually defined as 'a set of activities to achieve objectives'. It includes a sequence (cycle) of (i) analysis of the current situation and of possible options, (ii) decision making, (iii) planning of the activities, (iv) execution, (v) monitoring, and (vi) verification and control of achievements. These management activities relate to different components of the farm.

The purpose of the characterization of management discussed here is to relate the management to NUE, N output and N surplus. Hence, it should be a simple management characterization. As a first step, a distinction is made between crop management and livestock management.

<u>*Crop management*</u> is further divided in

- (i) crop rotation aspects, i.e. crop sequence, use of cover crops and under growth, use of legumes, use of buffer zones.
- (ii) soil cultivation aspects, i.e., conventional (mouldboard) ploughing or minimum tillage or zero tillage
- (iii) nutrient management, i.e., use of soil fertility analyses, organic farming, use of animal manures without low emission techniques, use of animal manures with low-emission techniques, use of fertilizers, use of GPS controlled fertilizer application, use of micronutrients or other additives.
- (iv) pest management, i.e., use of chemical control and/or biological control measures
- (v) irrigation and drainage aspects, i.e., no irrigation, sprinkler irrigation, flood irrigation, drip irrigation and/or fertigation

<u>*Livestock management*</u> is further divided in

- (i) animal categories, i.e., Dairy cattle – beef cattle – pigs – poultry – sheep - goats
- (ii) herd related aspects, i.e. number of dairy cattle, replacement heifers, calves for replacement, number of fattening and suckling cattle, number of sows and fattening pigs, number of broilers and laying hens
- (iii) feeding management, i.e., number of grazing days per year, kg of concentrate per dairy cow, percent protein in animal feed
- (iv) animal performance, i.e., milk production per cow per year (kg), calving interval (days), number of piglets per sow, feed conversion (kg feed per kg pork; kg feed per kg broiler; kg feed per kg egg)
- (v) animal health management, i.e., veterinary cost, in % of total costs
- (vi) manure management, i.e., solid manure or slurry, covered manure storages, manure export; m3 per year, low-emission manure application
- (vii) extensive or intensive

4.3. Characterization of climate

Climate encompasses the statistics of solar radiation, day length, temperature, humidity, atmospheric pressure, wind, rainfall, and other meteorological elemental measurements in a given region over long periods. The classical period considered to be reliable in statistical terms is 30 years, as defined by the World Meteorological Organization (WMO). Climate can be contrasted to weather, which is the present condition of these elements and their variations over shorter periods. Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation.

In the last decade climatic information has been linked to other environmental data, to arrive at a consistent classification (or stratification) of land into relatively homogenous strata. Environmental stratification differs from climatic stratification by using environmental strata that include more than simply climate characteristics. Climate affects life on earth, but life also affects climate. Hence, there are strong linkages and interactions between climate and the environment.

Below (Figure 2), an environmental stratification for European Union (EU) is presented based on climate, geomorphology, latitude, and oceanicity (the degree to which the conditions of a place are influenced by the sea). The stratification is based on statistical clustering. All together the clustering results in 13 different environmental zones (12 for EU, the other one is only in Turkey). Figure 2 shows a map of the environmental zones across Europe. Table 4 provides the names and abbreviations of the environmental zones. Table 5 summarizes the main climate characteristics for each zone.

The risks of N losses via ammonia volatilization, nitrate leaching and run off of nitrates and phosphate from agricultural land is also influenced by climate (environmental zones). Ammonia volatilization losses are high when temperature and humidity are relatively high and when there is no rainfall. Nitrate leaching, runoff and denitrification most likely occur under conditions of heavy rains, and when water inputs (rainfall + irrigation) exceeds evapotranspiration. Geomorphology and soil conditions also play an important role here (see section 4.4).

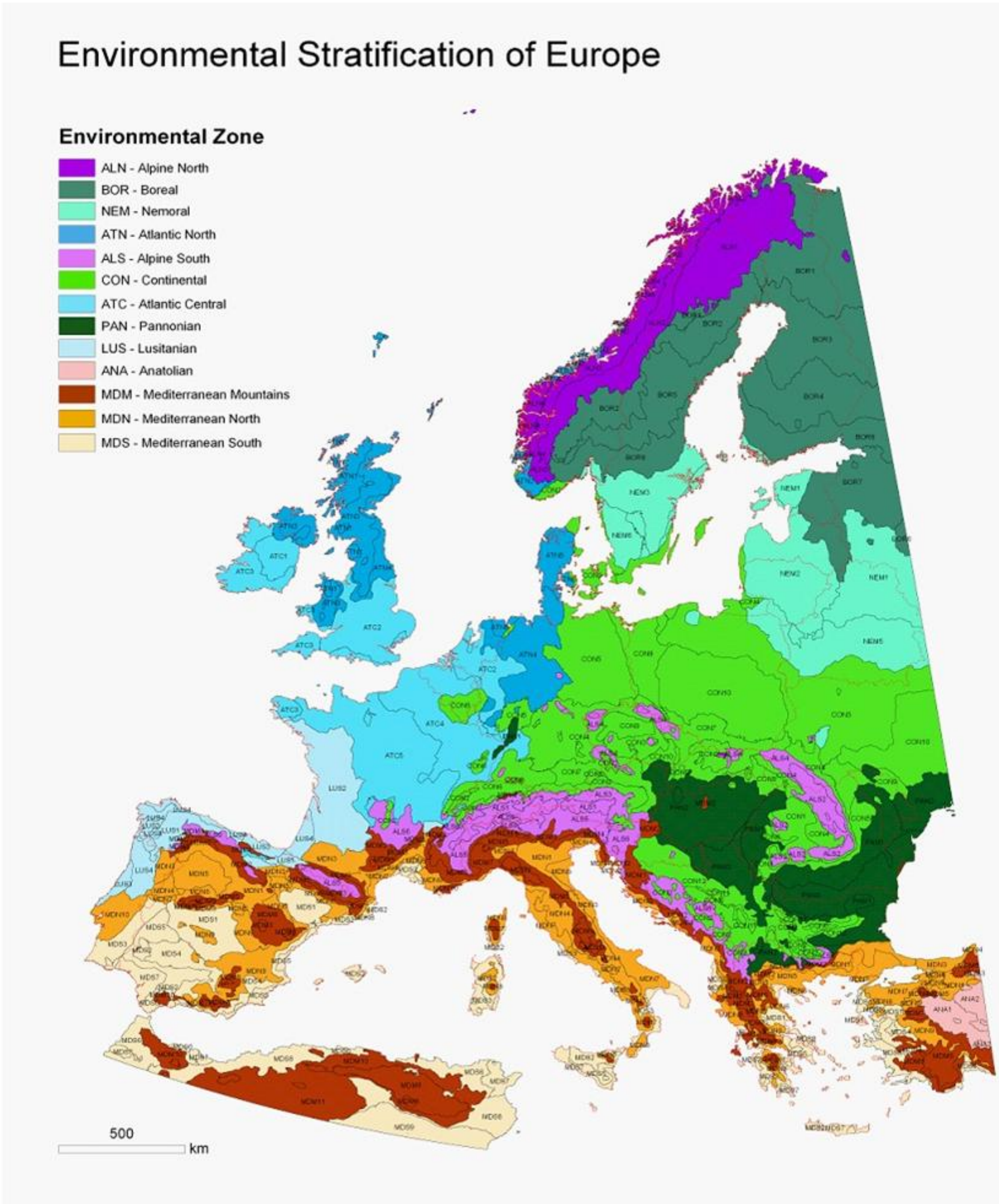

Figure 2. The Environmental Stratification of Europe (Metzger et al., 2005).

Table 4. The 13 Climatic Zones or Environmental Zones (EnZs).

Nr	Environmental Zone	Main locations and characteristics
1	Alpine North (ALN)	Scandinavian mountains
2	Alpine South (ALS)	The high mountains of central and southern Europe
3	Atlantic North (ATN)	NW Europe; under influence of the Atlantic ocean and the North sea
4	Atlantic Central (ATC)	Western Europe
5	Boreal (BOR)	The lowlands of Scandinavia
6	Continental (CON)	Central Europe; warm summers and cold winters
7	Lusitenean (LUS)	The southern Atlantic area; warm summers and mild winters
8	Mediterranean North (MDN)	Mediterranean north
9	Mediterranean Mountains MDM	Mediterranean mountains, influenced by Mediterranean and mountains
10	Mediterranean South (MDS)	Typical Mediterranean climate; mild winter and hot, dry summers
11	Nemoral (NEM	Southern Scandinavia, Baltic states and Belarus
12	Pannonian (PAN)	The steppe part of Europe; cold winters and dry hot summers
13	Anatolian (ANA)	The steppes of Turkey, a Mediterranean steppe environment

Table 5. Relative area in Europe, mean winter and summer temperature and rainfall and the number of days when the mean temperature is above 5 °C of the 13 Environmental Zones (EnZs).*

		Relative	Mean temperature, °C		#days	Mean rainfall, mm		
Nr	EnZs	area, %	Winter	Summer	Temp >5°C	Winter	Summer	**Total**
1	ALN	5	-6	6	130	504	432	936
2	ALS	5	1	11	220	475	614	1089
3	ATN	5	4	12	255	658	491	1149
4	ATC	8	6	14	296	437	389	826
5	BOR	14	-5	9	157	263	349	612
6	CON	20	2	15	227	270	415	685
7	LUS	3	9	16	353	622	406	1028
8	MDN	9	8	18	335	411	277	688
9	MDM	9	7	18	298	424	292	716
10	MDS	9	12	21	363	368	149	517
11	NEM	8	-1	13	196	276	374	650
12	PAN	7	4	18	250	231	337	568
13	ANA	1	3	12	n.a.	202	138	340

* Average values are presented, but the variation within zones can be large. For example, a mean annual precipitation of 516 mm for the MDS zone seems unrealistically high probably because this zone comprises some areas with high precipitation (i.e. Southwest of Iberian peninsula where total average annual rainfall >1000mm) and others with very low precipitation (i.e. East of Iberian peninsula (<200 mm), Sicily or Cyprus). This area could be sub-divided further into Mediterranean Oceanic, Mediterranean Continental, Subtropical and Arid. Hence, some zones may comprise areas where local mean values may greatly differ from the average.

4.4. Characterization of slope and soil conditions

Soil maps show the spatial distribution of soil types. Almost all countries have developed now their own soil characterization, classification, survey and mapping systems. As a consequence, soil types and soil maps identified and made in different countries are difficult to compare.

The first 'Soil Atlas of Europe' (Jones at al., 2005) is based on the World Reference Base for Soil Resources (WRB). A total of 25 of the 32 WRB soil types (reference groups) do occur in Europe. The soils with the largest extent are Albeluvisols that cover 15% of Europe; Podzols cover 14%, and Cambisols cover 12%. Overview maps in the Soil Atlas show the availability of soil maps at scales of 1:50,000 or 1:250,000 in Europe. It shows that large countries with large economies and populations (France, Germany, UK) do not have good coverage of detailed soil information. In fact, smaller and more densely populated countries have more detailed soil maps (with the exception of Denmark and Switzerland). There is an array of reasons, but in densely populated places there may have been a historical need to know the land characteristics as population pressure was higher. A map showing the European soils is shown in Figure 3. The 32 reference soil groups are listed in Table 6.

The most important soil characteristics for crop growth and environmental nitrogen losses are soil depth, slope, texture, soil organic matter and pH (Table 7). Soil depth is a combination of 'depth to rock', i.e., the depth at which rock is encountered in the soil profile, and 'depth to obstacles to roots', i.e., soil layers that restrict roots to permeate the soil such as rocks, impermeable soil layers and groundwater (reflecting soil drainage). The slope of the land does not so much affect crop growth (although the inclination toward the sun does), but it greatly affects field work and the risk of runoff and erosion. Soil texture refers to the proportion of the various particle-size classes. The soil texture in this case refers to the fine earth fraction (< 2 µm); it greatly affects the soil physical, chemical and biological properties of the soil, and especially the water holding capacity, cation exchange capacity, and nutrient retention and delivery. Soil organic matter and pH affect soil structure and also nutrient retention and delivery characteristics.

Table 6. The 32 reference soil groups of the World Reference Base for Soil Resources (WRB) and the first 'Soil Atlas of Europe' (Jones at al., 2005).

Brief description of soil type	Abbreviation
1. Soils with thick organic layers:	Histosols (HS)
2. Soils with strong human influence	
Soils with long and intensive agricultural use:	Anthrosols (AT)
Soils containing many artefacts:	Technosols (TC)
3. Soils with limited rooting due to shallow permafrost or stoniness	
Ice-affected soils:	Cryosols (CR)
Shallow or extremely gravelly soils:	Leptosols (LP)
4. Soils influenced by water	
Alternating wet-dry conditions, rich in swelling clays:	Vertisols (VR)
Floodplains, tidal marshes:	Fluvisols (FL)
Alkaline soils:	Solonetz (SN)
Salt enrichment upon evaporation:	Solonchaks (SC)
Groundwater affected soils:	Gleysols (GL)
5. Soils set by Fe/Al chemistry	
Allophanes or Al-humus complexes:	Andosols (AN)
Cheluviation and chilluviation:	Podzols (PZ)
Accumulation of Fe under hydromorphic conditions:	Plinthosols (PT)
Low-activity clay, P fixation, strongly structured:	Nitisols (NT)
Dominance of kaolinite and sesquioxides:	Ferralsols (FR)
6. Soils with stagnating water	
Abrupt textural discontinuity:	Planosols (PL)
Structural or moderate textural discontinuity:	Stagnosols (ST)
7. Accumulation of organic matter, high base status	
Typically mollic:	Chernozems (CH)
Transition to drier climate:	Kastanozems (KS)
Transition to more humid climate:	Phaeozems (PH)
8. Accumulation of less soluble salts or non-saline substances	
Gypsum:	Gypsisols (GY)
Silica:	Durisols (DU)
Calcium carbonate:	Calcisols (CL)
9. Soils with a clay-enriched subsoil	
Albeluvic tonguing:	Albeluvisols (AB)
Low base status, high-activity clay:	Alisols (AL)
Low base status, low-activity clay:	Acrisols (AC)
High base status, high-activity clay:	Luvisols (LV)
High base status, low-activity clay:	Lixisols (LX)
10. Relatively young soils or soils with little or no profile development	
With an acidic dark topsoil:	Umbrisols (UM)
Sandy soils:	Arenosols (AR)
Moderately developed soils:	Cambisols (CM)
Soils with no significant profile development:	Regosols (RG)

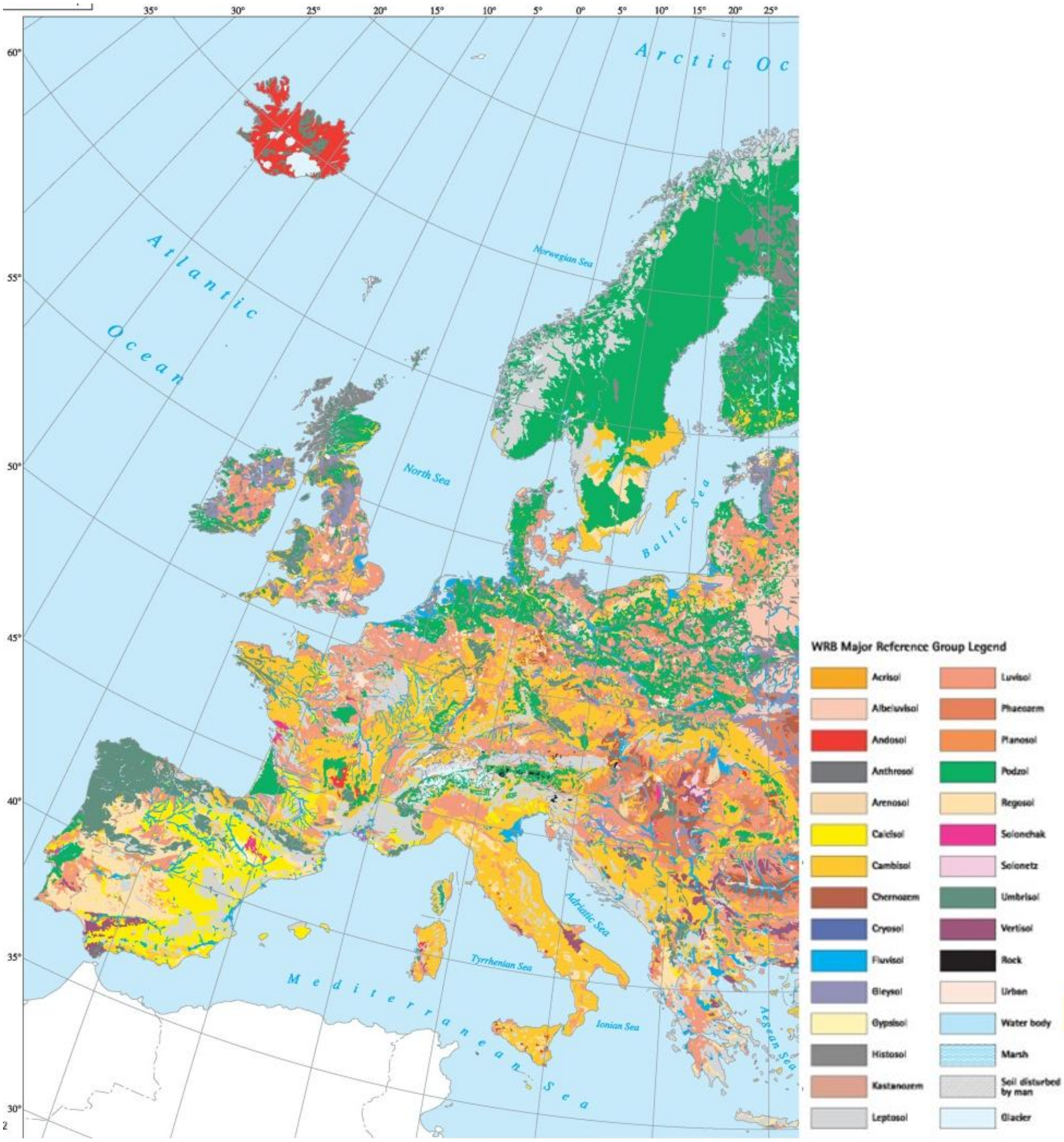

Figure 3. Map of European soils.

Table 7. Summary overview of important soil variables for crop growth and nitrogen losses.

Soil variable	Description
Soil Type	Reference soil group (see Table 6)
Slope	(1) Level (0 to 2 %), (2) Gently sloping (2-8%) (3) Sloping (8 to 15 %), (4) Moderately steep (15 to 25 %), (5) Steep (>25%)
Soil Depth	(1) Shallow (< 40 cm), (2) Moderate (40-80cm), (3) Deep (80-120cm), (4) Very deep (> 120cm)
Texture of top soil	(1) No mineral texture (Peat soils), (2) Very fine (clay > 60 %); (3) Fine (clay: 35 - 60%); (4) Medium fine (clay: 15 - 35%); (5) Medium (clay: 8 – 15%) (6) Fine sand (clay: 5 - 8% and <65% sand) (6) Coarse (clay: < 5 and > 65% sand)
Soil pH of topsoil	(1) Alkaline (pH>7.5) (2) Neutral (pH: 6 - 7.5) (3) Slightly acidic (pH: 4.5 – 6) (4) Acidic (pH<4.5)
Soil organic matter content of the topsoil of mineral soils	(1) High (> 5%) (2) Medium (3-5% (3) Modest (1-3%) (2) Low (< 1%)
Soil nutrient status	Based on soil phosphorus, potassium, sulphur, magnesium, micro-nutrients contents: (1) Low (2) Medium (3) High

5. Format for Reporting NUE, N output and N surplus at farm level

Ideally, farm reports have a common format, to ease the understanding of the report, and to facilitate comparison between farms. The basic (common) outline of the report is presented below in Box 1. In practice, there are large differences between farm types, especially between main types of farms, such as (i) arable farms, (ii) farms with livestock, including mixed livestock-crop farms, and (iii) farms with permanent crops (cropland), like fruit orchards, vineyards, olive yards. The differences between systems may warrant slightly adjusted/modified outlines of the reports.

Box 1. Common outline of the report

1. **Title**: "Nitrogen Use Efficiency of ... farms in ....in the years ...

2. **Introduction**
- main objectives (monitoring, improving NUE, ...)
- organization of the study (who were involved)

3. **Description of the region**
- Where in Europe (coordinates),
- Characterization of environmental zones and soil type and management (Table 7; annex 4)

4. **Characterization of the farms and its management**
- Number of farms
- Main characterization of farming types, (complete Table 3; annex 4)
- Characterization of the management (Annex 4)

5. **Data collection procedures**
- how, when and where were data collected
- who has done the data collection and processing

6. **Characterization of N inputs and outputs**
- What were main N inputs, N outputs and changes in N stocks
- Characterization of N balance (complete Table 1; Annex 4)
- Graphical presentation of NUE, N output and N surplus; presentation of results using Figure 1

7. **Discussion and Conclusions**
- about values and trends, and their relationships with farm type, soils, climate, management
- about uncertainties in values
- about possible changes in soil N content
- Suggestions for improving NUE

8. **References**

The next paragraphs provide further guidance to drafting reports about NUE, N output and N surplus at farm level.

5.1 Arable and vegetable farms

Arable farms are many in number (Table 2) and cover relatively large areas in the European Union. Originally, arable crops were defined by 'growing crops in ploughed soil', as contrast to permanent grassland and trees (orchards). This definition does not fit well for arable farms with zero tillage. The term 'farms with field crops' is also used for arable farms, where a field crop is defined as a 'crop (other than fruits or vegetables) that is grown for agricultural purposes in the field'. This definition may include crops for animal feeding, including hay and silage, but would exclude growing vegetables. Others though define field crops 'all crops grown in the field', as contrast to crops grown indoor (houses, greenhouses). Eurostat (2015b) has made a guidebook on nomenclature and definitions of crops grown in Europe. Most crops grown on arable farms are grown as annual crops, but some are grown as perennial crops like alfalfa and asparagus. Some crops are biennial plants, that take two years to complete the biological lifecycle (flower in the second year following a winter season).

Eurostat (2015b) distinguish some 70 different crops grown on arable farms. In addition, some 55 different vegetable crops are distinguished for vegetable farms. Some crops are grown in both arable farms and vegetable farms. Indeed, the difference between arable and vegetables farms is often relatively small; the area of vegetable farms is relatively small and the labor cost and marketable output per unit of land are relatively large. We use the term 'vegetable farms' here and not horticultural farms, as the latter term may include also fruits and nuts from orchards.

Typical for arable and vegetable farms is the growth of more than one crop in rotation. Crop rotations suppress soil-borne diseases and pest as well as weed infestations. As a result, yields of crops are usually higher when grown in rotation, compared to crops grown as monoculture year after year. Because of the importance of crop rotations, it is quite common that farmers do the nutrient management (including N management) per rotation (usually 3 to 6 years). They may apply more or less nutrients to a specific crop depending on the preceding crop. NUE, Noutput and N surplus determined at crop/field level may then give a biased result, depending on the other crops in the rotation and the N management. Therefore, NUE, Noutput and N surplus are preferably reported over a whole crop rotation. A description of both the type of crops grown as well as the crop rotation need to be reported, in combination with NUE, N output and N surplus. Also, a cover crop, green manure or catch crop may be grown after the harvest of the main crop, and ploughed down just before the planting of the next crop. In this case, the cover crop, green manure or catch crop may mop up residual nutrients left in the soil after the main crop, while the next crop may benefit from nutrients released from the cover crop, green manure or catch crop through mineralization. Further, two or three main crops may be grown on the same field in the same year (for example leafy vegetables as spinach and lettuce as monoculture, or in rotation with cabbages). Crops may be grown also as intercrops or as mixture, in which case it is also difficult to estimate NUE accurately per crop.

In summary, NUE, N output and N surplus of arable and vegetable farms should be reported at the farm level and preferably at the rotation level. A description of the crop rotation and crop types have to be provided. In specific cases, it may be interested for the farmer to estimate NUE, N output and N surplus also at field level for specific crops.

The report should follow the outline presented in Box 1. In section 4 of the report, the farm(s) will have to be characterized, using the five characteristics of the farm typology mentioned in Table 3. Section 6 then presents the N inputs and N outputs, using Table 1. For arable and vegetables farms, the most relevant N input and N output items are presented in Table 8 below.

The N input items are corrected for possible storage at the farmyard, i.e., only the amounts of planting material, fertilizers, manure, compost, and/or sludge applied to the land have to be recorded. Hence, the imported amounts of planting material, fertilizers, manure, compost, and/or sludge to the farm are corrected for possible changes in storage of these materials on the farmyard (or another possible storage location). The amounts of planting material, fertilizers, manure, compost, and/or sludge are multiplied by the N content of these items, which are preferably derived from analyses by certified laboratories used by the purchase company or from look-up tables in Annex 1.

All harvested crop products have to be recorded, even when the produce is temporary stored on the farmyard (and sold the next year). The weight of the harvest products is multiplied by the N content of the products, which are preferably derived from analyses by certified laboratories or from look-up tables in Annex 1.

Table 8. Common Input and output items for establishing the N balance of arable farms.

Nitrogen input items		Nitrogen output items	
Mineral fertilizers	I1	Crop products	O1
Biological nitrogen fixation	I3		
Atmospheric N deposition	I4		
Compost and sewage sludge	I5		
Seed and planting material	I6		
Animal manure (net)	I8		
Irrigation	I9		
Total		Total	

The total N input and output are expressed per unit of planted agricultural area. Hence, fallow land, buffer strips, focus areas are not included as agricultural land, unless these areas are an integral part of the crop rotation. The NUE, N output and N surplus are presented also as graph (see figure 1). Changes in soil N stocks (in the top 25 cm) should be reported and discussed relative to NUE.

Section 7 of the report (see Box 1) discusses the NUE, N output and N surplus of the farm in relation to (i) the farm characteristics and environmental conditions, and (ii) the possible reference or target values. Tentative target values have been mentioned in Figure 1 and discussed by the EU Nitrogen Expert Panel (2015), but these should be refined further. Section 7 also discussed possible uncertainties in the estimated NUE, N output and N surplus, and opportunities for enhancing NUE and N output and for decreasing N surplus.

5.2 Mixed crop – livestock farms

Mixed crop – livestock farms have both crop land and livestock (farm animals). These farms raise animals to produce milk, egg and meat from farm-grown feed, supplemented possibly with purchased animal feed. Some of these mixed crop –livestock farms may produce and sell also arable or vegetable crops, and or surplus animal feed.

There is a large variety in mixed crop – livestock farms in Europe. These farms include the specialist grazing livestock farms, the specialist granivores (landless farms with monogastric animals, including pigs and poultry, mixed livestock farms, and mixed crop-livestock farms listed in Table 2). Dominant farm types include grassland-based dairy and beef farms and cropland-based pig and poultry farms. Farms may differ in animal categories, in specialization and in the net purchase of animal feed (externalization). Animal categories distinguished in farm statistics and by Eurostat are listed in the EU *Regulation No 1165/2008 concerning livestock and meat statistics* (EC, 2008). In total some 30 categories are distinguished. Farms can be highly specialized. For example, specialized broiler farms import young chicks of few days old and raise these chickens till the desired weight in a few weeks, often on purchased feed. This cycle may be repeated 6 or 7 times per year. In contrast, fully integrated (closed) mixed crop –livestock farms sell only animals which are born on the farm, and these animals are raised on farm-produced animal feed. Mixed livestock farms have more than one main livestock categories and possibly also cropland. Mixed crop-livestock farms may sell also crop products next to animal products.

The NUE, N output and N surplus of mixed crop – livestock farms should be reported at farm level annually, with a description of the animal categories, the cropland area and crop types, as well as the relative externalization of animal feed. It may be interested and important also for enhancing NUE and N output and for decreasing N surplus, to estimate NUE, N output and N surplus also at levels of main animal categories and for the crop land. This specification of NUE, N output and N surplus at compartment level requires more recording and processing of data and information. Here, we focus on the farm level.

The report should follow again the outline presented in Box 1. In section 4 of the report, the farm(s) will be characterized, using the five characteristics of the farm typology mentioned in Table 3. Section 6 then presents the N inputs and N outputs, using Table 1. Likely, not all input and output items in Table 1 may be relevant for mixed crop –livestock farms, depending on the degree of specialization; most relevant ones are presented here below as Table 9.

The N input items are corrected for possible storage at the farmyard, i.e., only the amounts of fertilizers, animal feed, manure, compost, and/or sludge applied to the land have to be recorded. Hence, the imported amounts of animal feed, fertilizers, manure, compost, and/or sludge to the farm are corrected for possible changes in storage of these materials on the farmyard (or another possible storage location). The amounts of animal feed, fertilizers, manure, compost, and/or sludge are multiplied by the N content of these items, which are preferably derived from analyses by certified laboratories used by the purchase company or from look-up tables in Annex 1.

All harvested crop produce has to be recorded, even when the produce is temporary stored on the farmyard (and sold the next year). The harvest products are multiplied by the N content of the products, which are preferably derived from analyses by certified laboratories or from look-up tables in Annex 1. The weight of all animal products (milk, egg, wool) and animals sold to the market are recorded. For milk, the N content is derived from the mean protein content, which is quantified by the milk processer and reported on the declarations of the milk processor (N content = protein content / 6.38). Milk yields recorded at the milk processor have to be corrected for the consumption by the household members and for selling to nearby citizens.

Table 9. Input and output items considered for the N balance of mixed crop – livestock farms.

Nitrogen input items		Nitrogen output items	
Mineral fertilizers	I1	Crop products	O1
Feed and fodder (net)	I2	Animals (net)	O2
Biological nitrogen fixation	I3	Animal products (milk, egg, wool)	O3
Atmospheric N deposition	I4	Trees, branches (from agroforestry)	O4
Compost and sewage sludge	I5		
Seed and planting material	I6		
Bedding material (straw, saw dust)	I7		
Animal manure (net)	I8		
Irrigation	I9		

The total N input and output are expressed per unit of planted agricultural area. Hence, fallow land, buffer strips, focus areas are not included as agricultural land. The NUE, N output and N surplus are presented also in a graph (see Figure 1). Changes in soil N stocks (in the top 25 cm) should be reported and discussed relative to NUE. Such changes may be expected following the conversion of permanent grassland into crop land and vice versa. The monitoring of soil N stock changes over time requires specific sampling protocols, similar as monitoring changes in soil carbon stock changes within the framework of the UNFCCC (IPCC, 2006; Smith et al., 2012). In agro forestry systems N stock in trees may be relevant and estimates should follow carbon stock recommendations.

Section 7 discusses the NUE, N output and N surplus of the farm in relation to (i) the farm characteristics and environmental conditions, and (ii) the possible reference or target values. Tentative target values have been mentioned in Figure 1 and discussed by the EU Nitrogen Expert Panel (2015), but these should be refined further to account for the system, region and soils relevant to the specific values. Section 7 has to discuss also possible uncertainties in the estimated NUE, N output and N surplus, and opportunities for enhancing NUE and N output and for decreasing N surplus.

5.3 Permanent cropping systems and orchards

Permanent crops are 'ligneous crops', i.e. trees and shrubs that yield fruits, berries and nuts. These crops are not grown in rotation but are harvested for many consecutive years (usually more than five and in some cases more than fifty years). Permanent crops include fruit and berry trees, bushes, vines and olive trees, but excludes land under trees grown for wood or timber. Permanent crops generally yield a higher added value per hectare than annual (arable) crops. These crops also play an important role in shaping the rural landscape (through orchards, vineyards and olive tree plantations) and helping to balance agriculture within the environment (Eurostat, 2015a).

Permanent crops covered 5.9 % of the total utilized agricultural area in EU-28 in 2013, but in some countries like Spain permanent crops covered almost 20% of the total utilized agricultural area. There were 1.9 million agricultural holdings (farms) in the EU-28 in 2013 with specialist permanent cropping systems (17% of the total number of farms). This indicates that the average farm size of permanent cropping systems is smaller than the average farm size of all farms in EU-28 (Eurostat, 2015a).

The trees and shrubs commonly cover only part of the land. As a consequence, there is often undergrowth of grass, which is either mown and mulched, or removed/deleted mechanically or via herbicides, or grazed by sheep, goat and/or cattle. The nutrient removal of undergrowth harvest is likely nihil or negligible, but may be significant in extensively managed orchards, and then should be reported.

In the juvenile stage trees and shrubs invest in the root system, stems and twigs. During the first few years after the planting of young trees and shrubs, fruit yield and N output are therefore low, while the N input can be significant, indicating that NUE is low during this period. Mature trees and shrubs do invest much less in roots, stems and twigs, while fruit yield and NUE are relatively high during this growth stage. Through aging, fruit yields and NUE of mature trees and shrubs slowly decline over time, until the old trees and shrubs are uprooted and the orchard replanted. Evidently, the age (physiological stage) and management of the orchard have to be indicated when reporting about NUE, N output and N surplus of permanent cropping systems.

Trees and shrubs are commonly pruned every 1-2 years, and the twigs and branches may be removed as biofuel or chopped and left on the ground. The nutrient removal of harvested pruning is likely negligible, but can be significant in case the trees and shrubs are uprooted and removed, at the end of the life time of the orchard. In this case the N export through trees, twigs and stubble must be reported.

Trees and shrubs are commonly irrigated via drip irrigation, i.e., water is allowed to drip slowly on or in the soil close to the root zone of the trees and shrubs, through a network of valves, pipes, tubing, and emitters. Nitrogen and potassium fertilizers are often applied also via drip irrigation (fertigation). Hence, only a small portion of the total area of the land is irrigated and fertilized, to save water and nitrogen. The water and N use efficiency can be high in these cases (Qin et al., 2016; Quemada and Gabriel, 2016).

Fruits have a low protein (and therefore N) content. The protein content ranges from about 0.3% in apples to 0.6% in grapes, 0.8% in olives and 0.9% in oranges and peaches (all in fresh weight). Some exotic fruits like guavas have a relatively high protein content of 2.6%. The protein content of fruit does not vary much with N fertilization. As a result, the N output of fruit orchards is modest. With a high yield of 100 tons of apples per ha per year, the N output is only 30 to 40 kg per ha per year. With a yield of 50 tons of oranges per ha per year, the N output is about 50 kg per ha per year. In fruit orchards, significant amounts of N are cycled through leaves and small pruning from crop to soil and following mineralization and uptake through plant roots from soil and crop again. If this cycling is well managed (leaves and small pruning not removed), NUE can still be relatively high, even with a relatively low N output, because of the intense recycling of N in these systems.

Nuts have a relatively high protein content, ranging from 15 to 20%, which is equivalent to 2.4 to 3.2% N. With yields ranging roughly from 5 to 10 ton per ha per year on well-managed orchards, N output may range between 100 to 250 kg of N per ha per year.

In summary, NUE, N output and N surplus of permanent cropping systems should be reported at farm level, with a description of the permanent cropping system and crop types, the age of the trees or shrubs, and the management. When different fruit types are grown on the farm, it may be interesting for the farmer to estimate NUE, N output and N surplus also at orchard level.

The report should follow the outline presented in Box 1. In section 4 of the report, the farm(s) will be characterized, using also the five characteristics of the farm typology mentioned in Table 3. Section 6 then presents the N inputs and N outputs, using Table 1; the most relevant N input and output items are presented in Table 10 below.

The N input items are corrected for possible storage at the farmyard, i.e., only the amounts of fertilizers, manure, and compost applied to the land have to be recorded. Hence, the imported amounts of fertilizers, manure, and compost to the farm are corrected for possible changes in storage of these materials on the farmyard (or another possible storage location). The amounts of fertilizers, manure, and compost are multiplied by the N content of these items, which are preferably derived from analyses by certified laboratories used by the purchase company or from look-up tables in Annex 1.

All harvested crop produce (fruits and nuts) has to be recorded, even if the product is temporary stored on the farmyard (and sold the next year). The harvested products are multiplied by the N content of the product, which are preferably derived from laboratories analyses or from look-up tables in Annex 1.

The total N input and output are expressed per unit of planted agricultural area. Hence, fallow land, buffer strips, focus areas are not included as agricultural land. The NUE, N output and N surplus are presented also as graph (see figure 1). Changes in soil N stocks (in the top 25 cm) should be reported and discussed relative to NUE. Such changes may be expected following the uprooting of old orchards and planting of new orchards. The monitoring of soil N stock changes over time requires specific sampling protocols, because of the spatial variations in soil N in orchards. The soil sampling protocols used the monitoring of changes in soil carbon stock changes within the framework of the UNFCCC could be used (IPCC, 2006; Smith et al., 2012).

Table 10. Common input and output items for establishing the N balance of permanent cropping systems

Nitrogen input items		Nitrogen output items	
Mineral fertilizers	I1	Fruits and nuts	O1
Biological nitrogen fixation	I3	Trees, branches (net)	O4
Atmospheric N deposition	I4		
Compost and sewage sludge	I5		
Seed and planting material	I6		
Animal manure (net)	I8		
Irrigation	I9		
Total		Total	

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Annex 1. Look-up tables for N contents in input and output items for the Tier 1 approach

Annex 1; Table A1. Default N contents of imported and exported animal feed used in Europe (Dalgaard et al., 2012).

Material	Default N content (kg N Mg^{-1} fresh weight)
Beet pulp (dried)	14.4
Cereals	16.3
Eggs	18.1
Feed milk	56.3
Fertiliser nitrogen	1000.0
Fresh milk	5.0
Fresh green forage (alfalfa)	6.0
Fresh green forage (grass)	6.3
Fresh green forage (grass/clover)	5.7
Full-ration concentrate mix	25.6
Hay	16.0
High energy concentrate	52.2
Low energy concentrate	25.8
Medium energy concentrate	43.9
Meat (live animals)	46.0
Rape cake	49.3
Silage (alfalfa)	18.0
Silage (beet pulp)	3.8
Silage (clover grass)	9.1
Silage (grass)	8.5
Silage (maize)	3.9
Silage (whole crop)	6.0
Soy beans	56.4
Soybean oil cake	70.2
Straw	5.4
Sugar beets	2.1
Wet distillery grain	3.4
Whey	35.0
Whole crop fresh	5.8
Wool	3.0

Annex 1; Table A2. Default N contents of animal manures used in Europe (Dalgaard et al., 2012) for the Tier 1 approach

Manure type	Default N content (kg N Mg^{-1})
Cattle farmyard manure (FYM)	8.4
Composted manure/compost from other materials	2.0
Degassed cattle slurry	3.9
Degassed pig/mixed slurry	4.0
Horse FYM	7.5
Liquid fraction of cattle manure	5.4
Liquid fraction of mixed manure	5.0
Liquid fraction of pig manure	4.0
Mixed FYM	8.6
Mixed slurry	5.4
Other organic fertiliser (e.g. bone meal)	2.0
Pig FYM	8.8
Pig slurry (sows and piglets)	4.6
Pig slurry (fattening pigs)	5.4
Sewage sludge	6.0
Sheep/goat FYM	8.4
Solid fraction of cattle manure	5.6
Solid fraction of pig (fatteners) or mixed manure	5.9
Solid fraction of pig manure (sows + piglets)	8.1
Solid poultry manure	21.0

Annex 1; Table A3. Tier 1 N and P contents of crop products, in g kg^{-1} (FAO, 2004).

Crop products	N	P
Wheat	20.8	4
Barley	17	3.3
Maize	15.3	3.1
Rye	17.5	3.1
Oats	18.1	3.9
Millet	17.9	3.8
Sorghum	16.1	3.8
Cereals, Other	16.1	3.1
Potatoes	2.9	0.6
Cassava	4.3	0.8
Sweet Potatoes	3.7	0.6
Roots, Other	3	0.4
Yams	3	0.4
Sugar Cane	1.3	0.4
Sugar Beet	2.3	0.4
Sugar, Non-Centrifugal	8.3	0.9
Sugar (Raw Equivalent)	8.3	0.9
Sweeteners, Other	8.3	0.9
Molasses	8.3	0.9
Beans	42	4.9
Peas	50.7	5
Pulses, Other	50.7	5
Nuts	17.9	3
Soyabeans	58.6	7.9
Groundnuts (Shelled Eq)	41.9	3.6
Sunflowerseed	28.8	5.3
Rape and Mustardseed	35.2	6.1
Cottonseed	26.8	5.8
Coconuts - Incl Copra	5.7	1.3
Sesameseed	23.7	5.6
Palmkernels	4.9	0.7
Olives	1.6	0.1
Oilcrops, Other	23.7	5.6
Soyabean Cake	58.6	7.9
Groundnut Cake	41.9	3.6
Sunflowerseed Cake	28.8	5.3
Rape and Mustard Cake	35.2	6.1
Cottonseed Cake	26.8	5.8
Palmkernel Cake	4.9	0.7
Copra Cake	5.7	1.3
Sesameseed Cake	23.7	5.6

Oilseed Cakes, Other	23.7	5.6
Brans	8.3	0.9
Tomatoes	2.9	0.6
Onions	2.9	0.6
Vegetables, Other	2.9	0.6
Oranges, Mandarines	1.8	0.2
Lemons, Limes	1.8	0.2
Grapefruit	1.3	0.3
Citrus, Other	1.8	0.2
Bananas	1.7	0.3
Plantains	1.7	0.3
Apples	1.8	0.3
Pineapples	1.8	0.3
Dates	17.9	3
Grapes	1.3	0.3
Fruits, Other	1.3	0.3
Coffee	35	2.6
Cocoa Beans	21.2	5.7
Tea	8.3	0.9
Pepper	2.9	0.6
Pimento	2.9	0.6
Cloves	8.3	0.9
Spices, Other	8.3	0.9
Wine	0	0.2
Beer	0	0.2
Beverages, Fermented	0	0.2
Beverages, Alcoholic	0	0.2
Alcohol, Non-Food	0	0.2
Cotton Lint	26.8	5.8
Jute	4.5	0.5
Jute-Like Fibres	4.5	0.5
Soft-Fibres, Other	4.5	0.5
Sisal	4.5	0.5
Abaca	1.8	0.3
Hard Fibres, Other	4.5	0.5
Tobacco	8.3	0.9
Rubber	6.6	1.1
Rice (Paddy Equivalent)	15	2.9
Rice (Milled Equivalent)	15	2.9
Roots & Tuber Dry Equiv	3	0.4
Sugar, Refined Equiv	8.3	0.9
Groundnuts (in Shell Eq)	41.9	3.6
Sugar, Raw Equivalent	8.3	0.9

Annex 1; Table A4. Tier 1 N contents of animal products (FAO, 2004).

Animal products	N	P
Bovine Meat	28.3	1.7
Mutton & Goat Meat	21.3	1.7
Pigmeat	15.2	1.8
Poultry Meat	27	1.6
Meat, Other	23	1.7
Offals, Edible	23	1.7
Milk, Whole	4.7	0.9
Milk, Skimmed	4.7	0.9
Butter, Ghee	1.3	0.2
Cheese	39.9	5.1
Whey	1.2	0.8
Cream	3.3	0.6
Eggs	20.6	2.1
Honey	0.5	0
Meat Meal	23	1.7
Freshwater Fish	27	1.9
Demersal Fish	27	1.9
Pelagic Fish	27	1.9
Marine Fish, Other	27	1.9
Crustaceans	27	1.9
Cephalopods	23	1.7
Molluscs, Other	15	1.6
Meat, Aquatic Mammals	27	1.9
Aquatic Animals, Others	27	1.9
Aquatic Plants	27	1.9
Milk - Excluding Butter	4.7	0.9
Fish Meal	27	1.9

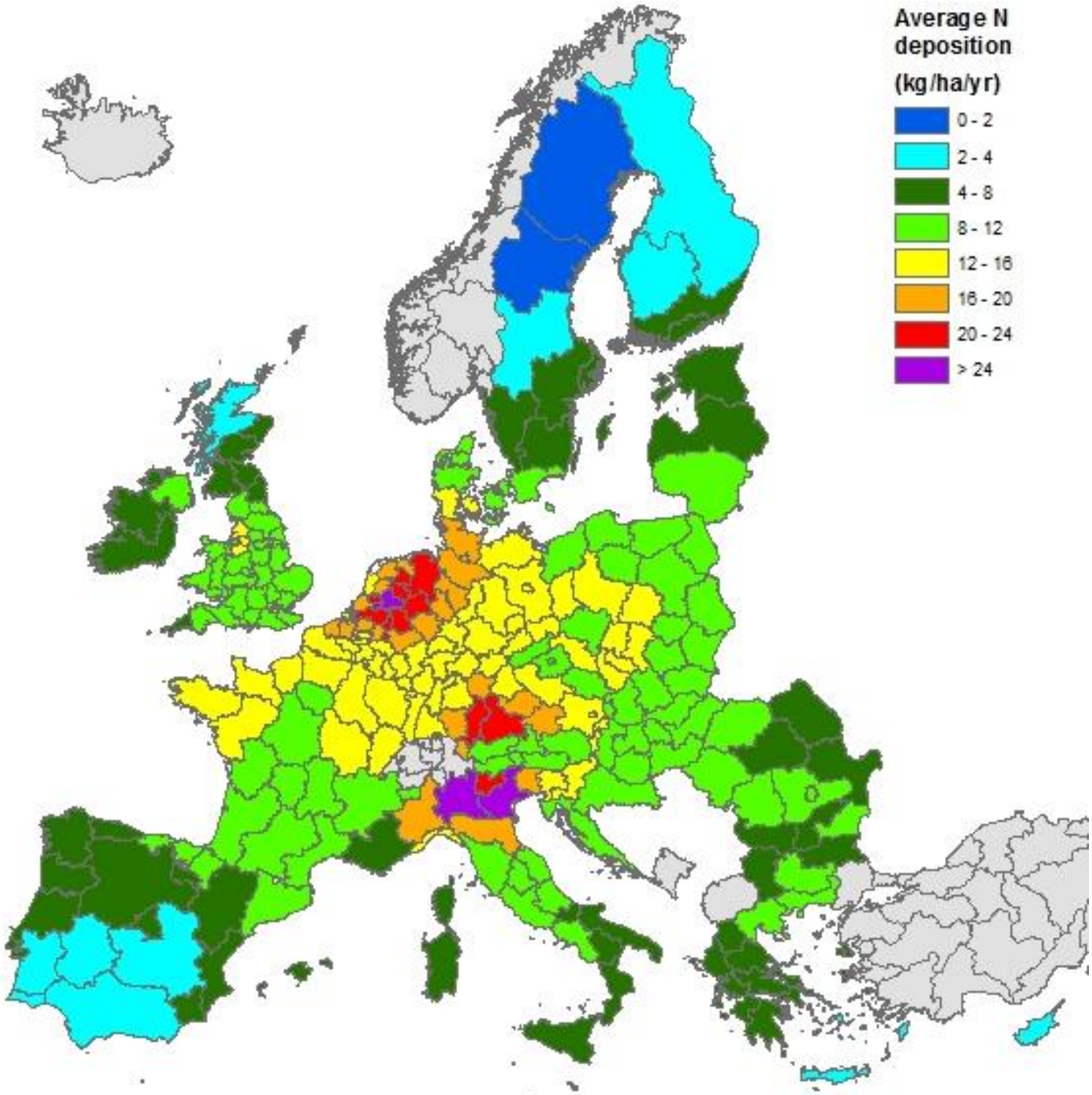
Annex 1; Table A5. Variations in default N contents of pigs in different countries for the Tier 1 approach

The table below provides an overview of the default N contents in pigs (fresh weights) used in different EU countries, according to formal reports. Some countries use one value for all pig categories, while other countries use different values for different categories. Values for France seem relatively low. Note that the N contents of animals depend on their genes and feeding, and further vary with the relative fractions of fat and bones, which may vary with the physiological age of the animals. These default values often date from many years ago, as they are not frequently updated and not easy to determine.

Category	Weight kg	Age	Denmark	France	Ireland	Italy	Germany	NL	UK
Dead born piglet	1.3	0 days	[1]	-	-	-	25.6	18.7	-
Culled piglet	2.8	1 – 28 days	[1]	-	-	-	25.6	23.1	-
Culled piglet	9	29 – 42 days	[1]	-	-	-	25.6	24.3	-
Weaned piglet	7	4 weeks	30.4	18.3	30.4	-	25.6	-	30.4
Weaned piglet	11	6 weeks	30.4	18.3	25	-	25.6	24.4	25
Culled piglet	12	7 weeks	30.4	18.3	-	-	25.6	24.5	-
Growing pig	26	10 weeks	29.6	18.5	25	24	25.6	24.8	25
Finishing pig	114	26 weeks	29.6	18.5	25	24	25.6	25	25
Rearing sow	125	7 months	25.7	-	22	-	25.6	24.9	22
Rearing sow	140	First mating	25.7	-	22	-	25.6	24.9	22
Rearing boar	135	7 months	25.7	-	27.4	-	25.6	24.9	27.4
Boar (breeding)	325	2 years	25.7	-	27.4	-	25.6	25	27.4
Breeding sow	220	At weaning	25.7	-	25.6	-	25.6	25	25.6
Sow at slaughter	220	1 wk after weaning	25.7	-	25.6	-	25.6	25	25.6

[1] is settled with the sows.

Annex 2. Mean atmospheric N deposition per NUTS-2 region in Europe during the period 2012-2014, in kg per ha per year. Source EMEP (http://www.emep.int/mscw/mscw_ydata.html#ASCIIdata).



Annex 3. Estimation of Biological N_2 fixation

The amount of N entering the farm via biological N fixation mainly depends on the type and area of the crops grown on the farm. Beans, peas, lupines, alfalfa and clovers are legumes (Leguminosae) and able to fix atmospheric N_2 in amounts that may range from less than 50 to more than 200 kg of N per ha per yr, depending also on soil type, climate and management. Dalgaard et al (2012) used common values across Europe of 100 kg N ha^{-1} yr^{-1} for peas, lupine and beans, 150 kg N ha^{-1} yr^{-1}) for alfalfa and grass/clover ley fields with more than 25% clover, and 20 kg N ha^{-1} yr^{-1} for grass/clover fields with a lower clover content. A more precise estimate for clovers follows from the estimation of the harvested dry matter yield of clover and the mean N content of the clover in mixed grass-clover swards, i.e. per ton dry matter 54 kg N (Van der Meer and Baan Hofman, 1989; Elgersma and Hassink, 1997). Recently, Anglade et al (2015) reviewed the international literature and came with more accurate estimations for all five main leguminous crops.

A tier- approach is proposed here, as follows:
Tier 1: General lookup table values, if nothing else is available (or can be used)
Tier 2: Simple regression relationships between BNF and exported (harvested) produce
Tier 3: Measurements of N_2 fixation

Table. Tier 1 approach: look-up numbers for biological N_2 fixation, in kg/ha/yr

Crop	Biological N_2 fixation, kg/ha/yr	
	Extensive systems	Intensive system
Alfalfa	150	250
Clover <25%	20	20
Clover >25%	150	250
Faba bean	50	100
Lentil	50	100
Pea	50	100

The Tier 2 approach is derived from Anglade et al (2015). The amounts of N_2 fixed (BNF, kg/ha/ha) are estimated from linear relationships with the amount of exported (harvested) dry matter (DM), or preferably from the amount of nitrogen in the exported produce (Noutput). Hence,

$$BNF = (a + b * Yield/HI) * BGN$$

where,

- BNF is the total N input via biological N_2 fixation (in kg N/ha/yr),
- Yield is the amount of harvested (exported) dry matter (ton/ha/yr) or the amount of nitrogen in harvested (exported) dry matter (kg/ha/yr),

- HI is the harvest index, defined as the ratio of the harvested (exported) biomass to the total aboveground biomass. For alfalfa and clover, the harvest index (HI) is set at 0.9, unless more precise estimates are available. For beans, lentils and peas, the harvest index (HI) is set at 0.7, unless more precise estimates are available.
- BGN is a correction factor for belowground N_2 fixation, comprising N associated with roots, nodules and rhizodeposition, set at 1.3 for lentils and peas, 1.4 for faba bean and 1.7 for forage legumes.

Hence,

BNF (Alfalfa) = (2 + 20.3 * DM Yield/0.9) * 1.7
BNF (Alfalfa) = (-14 + 0.81 * Noutput /0.9) * 1.7

BNF (Clover) = (14 + 25.6 * DM Yield/0.9) * 1.7
BNF (Clover) = (3 + 0.78 * Noutput /0.9) * 1.7

BNF (Faba bean) = (-13 + 20.5 * DM Yield/0.7) * 1.4
BNF (Faba bean) = (5 + 0.73 * Noutput /0.7) * 1.4

BNF (Lentil) = (-39 + 7.5 * DM Yield/0.7) * 1.3
BNF (Lentil) = (3 + 0.64 * Noutput /0.7) * 1.3

BNF (Pea) = (7 + 17.6 * DM Yield/0.7) * 1.3
BNF (Pea) = (4 + 0.66 * Noutput /0.7) * 1.3

Annex 4. Checklist for the data inventory.

Two sources of data can be used for estimating NUE, N output and N surplus at farm level, namely (i) primary data, i.e. collecting the data at farm level, from the farmer, and (ii) secondary data, i.e. collecting the data from accountant reports and other inventory reports. Often, a combination is used, i.e. a combination of primary and secondary data. Using secondary data is efficient, but the accuracy and validity should be known. This annex deals with collecting primary data. It may serve as a checklist.

To understand and properly interpret farm performance and efficiency it is essential to know the structure of the farm and the environment. The performance, management and strategy of the farm can be determined on the basis of descriptive data and interviews. To be able to compare information between farms, the data and information need to be collected in a uniform format, preferably with a standardized Excel file. Data to be collected and the use of units and codes must be clearly defined to avoid ambiguity. The data and information to be collected can be categorized into five main topics: (1) farm system & strategy, (2) climatic & soil characterization, (3) crop management (4) livestock management, and (5) nitrogen balances. Each of these topics is again sub-divided into sub-topics (Fig. A2, and Table A7).

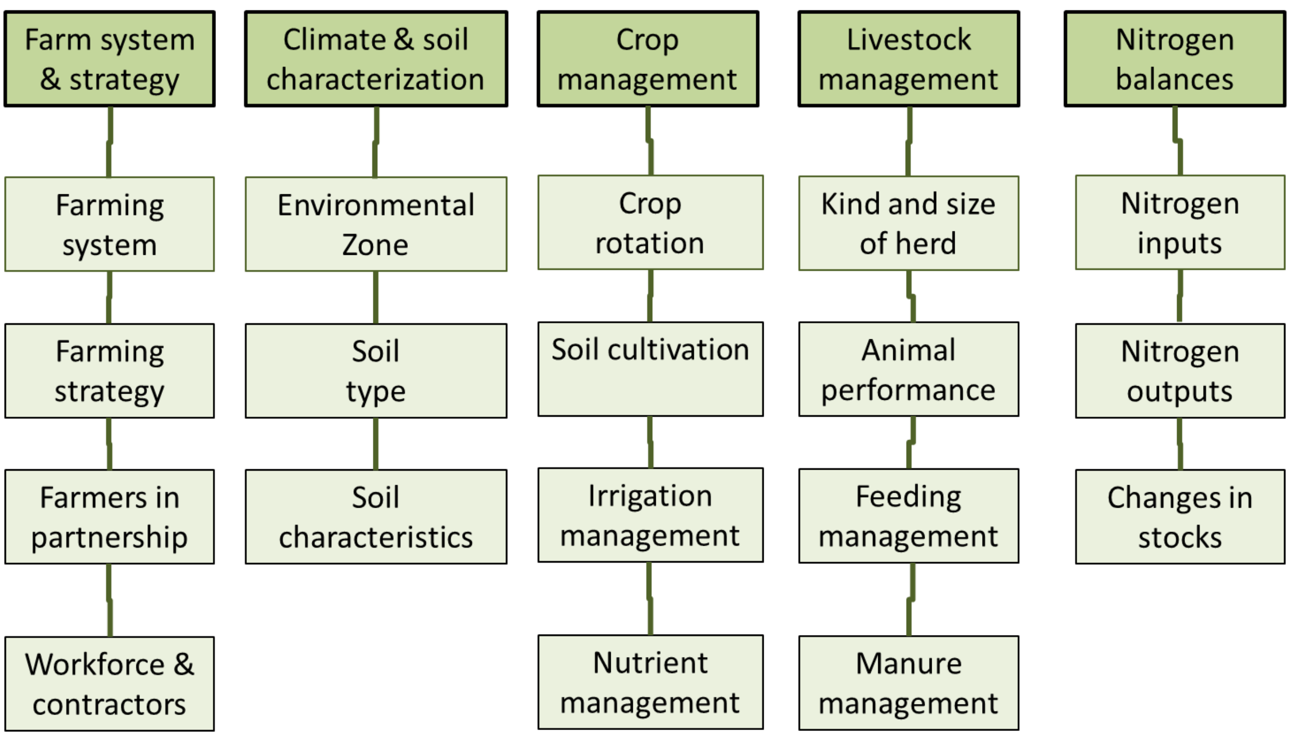


Figure Annex 4. Overview of the type of farm data and information to be collected

Table annex 4. Data and information to be collected for the different topics and sub-topics for the establishment of N balances.

Characterization of N inputs and N outputs

	Nitrogen balances[4]	
1	Inputs of nitrogen	• Net import of fertilizer N, kg N per yr • Net import of manure N, kg N per yr • Net import of compost N, kg N per yr • Net import of seed/plant N, kg N per yr • Net import of feed N, kg N per yr • Net import of bedding material N, kg per yr • Atmospheric deposition, kg per ha per yr (see annex 2) • Biological N_2 fixation, kg per yr (see Annex 3) • Irrigation Input of N, kg per yr
2	Outputs of nitrogen	• Net export of harvested crops, kg N per yr • Net export of milk produced, kg N per yr • Net export of live animals, kg N per yr • Net export of tress, branches and twigs, kg N per yr
3	Change in N stock	• Storage of harvested crop, kg N per yr • Storage of fertilizer N, kg N per yr • Storage of animal manure, kg N per yr • Storage of animal feed, kg N per yr • Number and mass of animals, kg N per yr • Mass of nitrogen in soil, kg N per yr[5]

[4] Inputs and outputs of N at farm level as well as changes in stocks are estimated for each product, using product-specific N contents. The amount (weight) of the products follow from the farm records (purchase and sales invoices). The appropriated N content of the products has to be derived from a three-tier-approach, as follows:
Tier 1: General lookup table values, if nothing else is available
Tier 2: Local/national and validated lookup table values in accessible reports
Tier 3: Local product N analyses
In the report, the tier number is reported.

[5] Changes in the soil N stock cannot be derived easily. Two approaches may be used, (i) measured changes in soil N derived from repeated analysis of the soil N stock over a period of minimal five years, which minimal four measurements, and (ii) calculated changes in soil N stock, using simulation models, which have been used extensively by different research groups for at least 5 years, while the results of the simulation models have been generally accepted by the scientific community as follows from at least five publications in peer reviewed scientific journals.

Characterization of farm types

1	Farm system and strategy	
1.1	Specialisation	Choose one of the following farm types, and indicate the percentage of the output from the main activity: (i) arable farms, (ii) horticultural farms, (iii) permanent crops, (iv) dairy farms, (v) beef farms, (vi) pig farms, (vii) poultry farms, (viii) sheep and goat, (ix) mixed livestock, (x) mixed farms (all other farms)
1.2	Land use	Dominant crop rotation and crop types, in %
1.3	Size of the farm	• Value of Standard Output (SO), • utilized area, in ha
1.4	Intensity	Value of Standard output per utilized area, in Euro per ha
1.5	Externalization	Purchased feed, in % of total feed

Characterization of crop management

Nr	Crop management	Aspects
1	Crop rotation	• Crop rotation sequence • Use of cover crops and under growth: yes/no • Use of legumes: yes/no • Use of buffer zones: yes/no
2	Soil cultivation	1. conventional (mouldboard) ploughing 2. minimum tillage 3. zero tillage
3	Nutrient management	1. use of soil fertility analyses 2. use of low-emission techniques 3. use of animal manures 4. use of enhanced fertilizers (slow release, inhibitors) 6. use of GPS controlled fertilizer application and trafficking
4	Pest management	1. Use of chemical control 2. Use of biological control
5	Irrigation & drainage	1. Well drained – moderately drained – poorly drained 1. no irrigation; - 2. sprinkler irrigation - flood irrigation - drip irrigation/ fertigation

Characterization of animal management

Nr	Animal management	Aspects
1	Animal category	Dairy cattle – beef cattle – pigs – poultry – sheep - goats
2	Animal numbers	• Number of dairy cattle - heifers - calves • Number of beef and suckling cattle • Number of sows – fattening pigs • Number of broilers – laying hens • Numbers of sheep - goat
3	Feeding management	• Farm grown feed - Purchased feed (%) • Protein in animal feed, % • Concentrates, kg per dairy cow • Grazing, number of days per year
4	Animal performance	• Milk production, kg per cow per year • Calving interval (days) – mean age of herd • Number of piglets per sows • Feed conversion; kg feed per kg pork • Feed conversion; kg feed per kg broiler • Feed conversion; kg feed per kg egg
5	Animal health	Veterinary cost, in % of total costs
6	Manure management	• Solid manure or slurry? • Covered manure storages? • Manure export; m^3 per year

Characterization of climate

Nr	Climate characterization	Aspect
1	Environmental zone	Choose the appropriate environmental zone (see Fig 2):
2	Weather conditions during the monitoring period	• Annual rainfall • Rainfall during the growing period • Mean summer temperature • Sowing time and harvesting time

Characterization of soil type

Nr	Soil characterization	Aspect
1	Soil type	Choose the dominant soil type
2	Slope	Define the average slope on the farm: (1) Level (0 to 2 %); (2) Gently sloping (2-8%); (3) Sloping (8 to 15 %); (4) Moderately steep (15 to 25 %); (5) Steep (>25%)
3	Soil Depth	Record the mean soil depth: (1) Shallow (< 40 cm), (2) Moderate (40-80cm), (3) Deep (80-120cm), (4) Very deep (> 120cm)
4	Texture of top soil	(1) No mineral texture (Peat soils), (2) Very fine (clay > 60 %); (3) Fine (clay: 35 - 60%); (4) Medium fine (clay: 15 - 35%); (5) Medium (clay: 8 – 15%) (6) Fine sand (clay: 5 - 8% and <65% sand), (6) Coarse (clay: < 5 and > 65% sand)
5	Soil pH of topsoil	(1) Alkaline (pH>7.5), (2) Neutral (pH: 6 - 7.5), (3) Slightly acidic (pH: 4.5 – 6), (4) Acidic (pH<4.5)
6	Soil organic matter content of the topsoil of mineral soils	(1) High (> 5%), (2) Medium (3-5%), (3) Modest (1-3%) (4) Low (< 1%)
7	Soil nutrient status	Low – medium - high