MARGINAL LANDS, INDUSTRIAL CROPS AND INNOVATIVE BIO-BASED VALUE CHAINS

# Deliverable D3.5 Description of farm-scale environmental indicators

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| Authors | Alexandro Ferreira (UNIBO), Andrea Monti (UNIBO),<br>Ana Luísa Almaça da Cruz Fernando (FCT UNL) |
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# Executive summary

This deliverable presents the farm-scale environmental indicators developed under Task 3.3 of the MIDAS project. These indicators aim to assess the environmental benefits and biodiversity impacts of the innovative farming systems proposed in the MIDAS project. The assessment framework follows the Driving Force-Pressure-State-Impact-Response (DPSIR) model proposed by the European Commission, allowing for a comprehensive evaluation of the sustainability of the Case Study (presented in Deliverable 3.1: *Results from the Case Studies of the Cropping Systems*).

The selected indicators analyze key dimensions, including land use, input use, productivity and biodiversity. These indicators will also be applied in WP5 to generate essential data and insights to assess the impact on biodiversity and restoration potential resulting from the adoption of MIDAS cropping systems. By integrating these indicators, the MIDAS project provides a robust toolkit for assessing the sustainability of innovative cropping system.

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# 1. Introduction

The primary objective of **Task 3.3**, *Farm-scale environmental indicators to assess the beneficial effects of the new cropping systems including biodiversity effects*, is to define and implement a comprehensive set of farm-scale environmental indicators designed to evaluate the environmental benefits and biodiversity impacts of the innovative cropping systems proposed under the MIDAS project. These indicators aim to provide practical tools for measuring the effectiveness of these innovations in promoting agricultural sustainability. Specifically, they assess the impact of these cropping systems by evaluating agro-environmental sustainability across different key dimensions: land use, fertilizer use, pesticide use, productivity and biodiversity. This multi-dimensional approach ensures a holistic evaluation of the potential of these new systems to improve environmental performance and sustainable farming practices.

The indicators selected for Task 3.3 are drawn from both the relevant literature and the list of 28 agri-environmental indicators proposed by the European Commission (European Commission, 2024). These indicators are framed within the DPSIR framework (Driving Force-Pressure-State-Impact-Response) a conceptual model that examines the complex interactions between human activities and environment.

The DPSIR framework organizes indicators into five categories:

- **Driving Forces**: Activities, such as agricultural practices, that initiate environmental changes.
- **Pressures**: Factors like pollution or resource depletion resulting from human activities.
- **State**: The current condition of environmental resources, such as soil or water quality.
- **Impacts**: The consequences of environmental changes on ecosystems, biodiversity, or human well-being.
- **Responses**: Actions, policies, or management practices implemented to mitigate or adapt to these changes.

From the 28 indicators defined by the European Commission, this task focuses specifically on those related to farm management practices, particularly those within the Driving Forces and Pressures domains.

Within the MIDAS project, the driving forces that could encourage the adoption of the cropping systems proposed are: the growing demand for sustainable bioproducts**,** potentially driving the adoption of industrial crops to supply biomass for bio-based products and support the transition to a greener economy (Popp et al., 2021), (Lewandowski, 2015); the valorization of marginal lands**,** which could help avoid competition between food and non-food crops while promoting the sustainable use of underutilized or degraded areas (Von Cossel et al., 2019), (Burland & von Cossel, 2023), (Stolarski, 2021).

Given the above reasons, driving forces can be considered the underlying factors that initiate changes in agricultural practices and systems, driving decisions toward more sustainable approaches. Therefore, driving force indicators include inputs such as land use planning, agricultural practices, chemical use, and energy consumption. On the other hand, pressure indicators reflect the results of these activities, highlighting their environmental impacts (Gaudino et al., 2014).

This distinction allows for a clearer analysis of how agricultural activities influence sustainability and environmental performance.

The selected indicators are organized as follows:

1. Domain: **Driving Force**

Sub-domain: **Farm Management**

- Soil Cover
- Tillage Practices

Sub-domain: **Land Use**

- Crop Diversity
- Crop Variability Index (CVI)
- Crop Cultivar Diversity (CCD)
- Cropping intensity
- Percentage of Hedgerows, canals and ditches; trees and shrubs

Sub-domain: **Input Use**

- Fertilizer consumption
- Pesticide consumption

2. Domain: **Pressure and Risk**

Sub-domain: **Pollution**

- Nitrogen Use Efficiency (NUE) and Phosphorus Use Efficiency (PUE)
- Pesticide risk

Sub-domain: **Productivity**

- Yield Index (YI)
- Land Equivalent Ratio (LER)

The following sections will provide a detailed explanation of each indicator, including their relevance, calculation methods, and how they contribute to assessing the sustainability of the proposed cropping systems.

# 2. Indicators

## 2.1. Driving forces

### 2.1.1. Farm management

#### 2.1.1.1. Soil cover

The **Soil Cover** indicator measures the number of days per year during which farmland is covered by vegetation or plant residues (European commission, 2024). Higher soil cover reduces surface runoff, which in turn minimizes soil erosion and the transport of nutrients and contaminants into waterways (Zhou et al., 2008). Within the MIDAS project where the farmland is under agroforestry or strip intercropping system, soil cover must be assessed by considering both the fraction of perennial cover, which focuses on perennial plants such as trees, and the fraction of annual cover, which includes annual crops. To calculate the total soil cover, a weighted approach should be applied. This involves considering the contribution of each component (e.g., trees and annual crops) based on their respective coverage and area within the farmland.

The fraction of perennial cover provides continuous protection throughout the year due to the presence of trees or perennial grass, while annual cover depends on the crop growth cycles (emergence to harvest) and the portion of land allocated to each crop.

Total Soil Cover formula:

$$Soil\ Cover\ (total) = SC\ (perennial) + SC\ (annual)$$

Where:

- *Soil cover (total)*: is the weighted total annual soil cover;
- *SC (perennial)*: is the fraction of soil covered by perennial species (constant throughout the year);
- *SC (annual)*: is the fraction of soil covered by annual crops, weighted by their presence on the field.

Calculation of the annual soil cover fraction:

$$SC\ (annual) = \sum_{i=1}^{n} \left( \boldsymbol{Ai} * \frac{\boldsymbol{di}}{\boldsymbol{365}} \right)$$

Where:

- *Ai*: is the fraction of soil occupied by the annual crop within the strip intercropping system;
- *di:* is the number of days in which the crop is present in the field (from emergence to harvest);
- *n*: is the total number of annual crops in the system.

The perennial soil cover fraction (SC (perennial) representing the constant fraction of soil covered by perennial species (e.g. perennial grasses or trees) throughout the year. It is expressed as a proportion of the total field area.

#### 2.1.1.2. Tillage Practice

The **Tillage Practice** indicator refers to the tillage operations performed between harvest and the subsequent sowing or cultivation (European Commission, 2024). It is calculated as the percentage of land, measured in hectares, managed using one of the specified tillage techniques. Tillage methods can be categorized into three types: conventional tillage, which involves intensive soil disturbance; minimum tillage, which reduces the degree of soil manipulation; and zero tillage, where soil is left undisturbed apart from seeding. Measuring tillage practices is important because soil disturbance significantly impacts soil structure, organic matter, and the soil's biological community. Reduced tillage practices, such as minimum and zero tillage, minimize disturbance to the soil structure and its organisms, concentrating organic matter at the surface where it breaks down more slowly. This increased organic matter, enhances water infiltration and storage capacity while promoting the activity of beneficial organisms, such as fungi and bacteria, which decompose organic matter in the upper soil layers and gradually releasing nutrients.

Additionally, increased earthworm activity contributes to improving soil structure and overall soil functioning (European Commission. Directorate General for Environment. & Wageningen Environmental Research., 2022).

The formula is:

$$TP = \frac{A\ (technique)}{A\ (total)} * 100$$

Where:

- *TP*: is the percentage of land under a specific tillage practice (e.g., conventional, minimum, or zero tillage);
- *A (technique)*: is the area of land (in hectares) managed using the specified tillage practice;
- *A (total):* is the total agricultural land area (in hectares) being assessed.

### 2.1.2. Land use

#### 2.1.2.1. Crop Diversity

The **Crop Diversity** refers to the number of different species cultivated within a year, reflecting the structural biodiversity of a cropping system (Gaudino et al., 2014). It is calculated as the total number of species grown for agricultural purposes. Diversification in time and space is essential to further enhance biodiversity. Temporal diversification involves crop rotation over time, while spatial diversification involves growing multiple species in a single filed. These practices not only increase structural biodiversity, but also support functional biodiversity by fostering a diverse range of organisms and ecological interactions, ultimately contributing to a more resilient and sustainable cropping system (European Commission. Directorate General for Environment. & Wageningen Environmental Research., 2022). When assessing crop diversity in case study areas, it is also important to consider the broader agricultural and ecological context. Identifying the most important and relevant species grown in and around the case study fields provides insights into key biodiversity drivers and agricultural practices in the region.

In addition, understanding the crops grown in neighboring fields can help assess potential interactions, such as pest or disease dynamics, as well as opportunities to improve biodiversity at the landscape level. Naturally valuable species in the area should also be documented, as their presence could indicate ecological corridors or critical habitats that contribute to biodiversity and ecosystem services. Similarly, the potential presence of invasive species, which could negatively impact local ecosystems and agricultural productivity, should be assessed. Ecological corridors, if present, could provide important connectivity between habitats, supporting the movement and survival of native species. This broader contextual information can strengthen the assessment of crop diversity by ensuring that indicators reflect not only farm-level practices but also landscape-level ecological dynamics.

#### 2.1.2.2. Crop Variability Index (CVI)

The **Crop Variability Index** is a useful indicator for assessing crop diversity within an agricultural system, considering the number of crops grown in a specific period, such as a year or an entire crop rotation cycle. It is an effective tool for distinguishing monoculture systems from more diverse ones, providing a quantifiable measure of the intensity and variability of crop rotation (Vanino et al., 2022). The CVI is calculated as the ratio between 1 and the number of crops growing in a year or years of rotation. Values equal to 1 indicates that there is a monoculture, while a value equal or lower than 0.5 indicates the presence of a rotation or intercropping.

The formula is:

$$CVI = \frac{1}{An}$$

Where:

- $An$: number of crop growing in a year.

#### 2.1.2.3. Crop cultivar diversity (CCD)

The **Crop Cultivar Diversity** indicator measures the diversity of cultivars within the crop species on a farm. It is calculated as the ratio between the total number of commercial cultivars and the Crop Diversity which represents the number of different crop species on the farm. A higher CCD indicates that, on average, each crop species is represented by more cultivars, suggesting greater genetic diversity, while a lower CCD indicates fewer cultivars per species, implying limited variation. However, CCD has limitations in that it does not reveal the distribution of cultivars among species; for example, a high CCD could result from the fact that one species has many cultivars while others do not, potentially distorting the diversity assessment. Therefore, CCD should always be interpreted together with Crop Diversity to obtain a balanced understanding of species and cultivar diversity (Last et al., 2014).

The formula is:

$$CCD = \frac{N\ (cultivars)}{N\ (species)}$$

- *N (cultivars)*: is the total number of commercial cultivars present on the farm;
- *N (species)*: is the total number of different crop species on the farm (Crop Diversity).

#### 2.1.2.4. Cropping intensity (CI)

Cropping intensity is defined as the ratio of total cropped or harvested land to the total cultivated or arable land over a specific period of time. It represents the number of crops grown on the same piece of land within a given time frame (e.g., 2 years). Cropping systems that promote intensive cropping generate more biomass and enhance plant diversity, leading to improved soil conditions for crop production compared to less intensive systems. Examples of intensive cropping practices include reducing fallow frequencies and planting multiple crops in rotation.

Conversely, practices such as continuous tillage, extended fallow periods, and reductions in cropping intensity and diversity contribute to soil degradation and lower productivity.

The formula is:

$$CI = \frac{Number\ of\ crops}{Unit\ of\ land}$$

Where:

- *Number of crops*: is the number of crops grown on the land over the specific period (e.g.1 year);
- *Unit of land*: is the total area of land used for cultivation (measured in hectares).

#### 2.1.2.5. Percentage of Hedgerows, canals and ditches; trees and shrubs

The inclusion of semi-natural vegetation elements (e.g., hedgerows, canals and ditches, trees and shrubs) within agricultural landscapes increases their capacity to provide multiple ecosystem services and their positive impact on biodiversity is widely recognized (Van Vooren et al., 2018). These elements serve as sources of food, nesting places, and refuges for natural enemies of pest insects and pollinators, while also providing habitats where natural enemies can overwinter. Additionally, they filter pollutants from soil, water, and air, thereby helping to prevent eutrophication. The indicator could be represented by the presence, length, and area of linear features such as hedgerows, canals and ditches, tree and shrubs (European Commission. Directorate General for Environment. & Wageningen Environmental Research., 2022). This indicator captures the distribution of semi-natural vegetation elements that contribute to ecosystem services and biodiversity within agricultural landscapes. It is quantifiable and aligns well with the role of these elements in supporting ecological functions.

### 2.1.3. Input Use

#### 2.1.3.1. Fertilizer consumption

The fertilizers consumption is the total amount of fertilizer (N,P,K) applied to a hectare (kg $ha^{-1}$). Nitrogen and phosphorus fertilizers greatly enhance crop production, but excessive use may lead to losses of these nutrients to the environment, contributing to environmental pollution (European Commission, 2024).

The formula is:

$$FC\ (N, P, K) = \frac{F\ (total)}{A\ (land)}$$

Where:

- *Fc (N,P,K)*: is the fertilizer consumption (kg $ha^{-1}$);
- *F (total)*: is the total amount of fertilizer applied (Nitrogen (N), Phosphorus (P), and Potassium (K), in kilograms);
- *A (land)*: is the unit of land where the fertilizer is applied (in hectares).

#### 2.1.3.2. Pesticide consumption

The indicator is the pesticides use defined as the total active ingredient quantity applied to a hectare (kg $ha^{-1}$) (Gaudino et al., 2014).

The formula is:

$$PC = \sum_{i=0}^{n} \frac{ARai}{A\ (land)}$$

Where:

- *N*: number of active ingredients applied in a year;
- *ARai*: dose of active ingredient applied (kg a.i. per hectare);
- *A (land)*: is the unit of land where the pesticide is applied (in hectares).

## 2.2. Pressure and risk

### 2.2.1. Pollution

#### 2.2.1.1. Nitrogen Use Efficiency (NUE) and Phosphorus Use Efficiency (PUE)

The **Nitrogen Use Efficiency** indicator assesses how effectively agricultural production converts applied nitrogen fertilizer into harvested products. The NUE is calculated as the ratio of nitrogen removed from the crop to nitrogen applied. It provides guidance on the use of supplemental nitrogen in an agricultural system (Brentrup & Palliere, 2010), (Oenema et al., 2015). When comparing NUE between different systems, it is essential to clearly define boundaries and consider residual nitrogen from fertilizer and manure, as it can benefit future crop cycles. Neglecting these aspects can lead to inconsistent or inaccurate comparisons (Hutchings et al., 2020).

**Phosphorus Use Efficiency** in an agricultural production system is defined as the ratio of the mass of phosphorus harvested in agricultural products and the mass of total phosphorus inputs into the system over a given period. PUE in crop production systems serves as a crucial indicator for evaluating phosphorus management in agricultural systems (Biswas Chowdhury & Zhang, 2021).

The formula is:

$$NUE\ (N, P) = \frac{Crop\ nutrient\ uptake}{Total\ nutrient\ applied}$$

Where:

- *NUE*: Nutrient Use Efficiency;
- *Crop nutrient uptake*: is the Nutrient Concentration in the crop biomass.

#### 2.2.1.2. Pesticide risk

The **Load Index (LI)** is an indicator that measures the potential impact of a chemical application on non-target organisms. It is the sum of the application rate (AR) of an active substance divided its toxicity, expressed through **LD50** (lethal dose for 50% of a population) or **LC50** (lethal concentration for 50% of a population) for a number of non-target taxa such as birds, mammals, fish, algae and agricultural beneficial insects like bees and natural enemies of pests (Gaudino et al., 2014), (Kudsk et al., 2018), (Catarino et al., 2024).

### 2.2.2. Productivity

#### 2.2.2.1. Yield index (YI)

The assessment of sustainable cropping systems must take productive performance into account. The **Yield Index**, as utilized by (Vanino et al., 2022) can be adapted to evaluate and compare crop performance in marginal systems within the MIDAS project against optimal growing conditions in the same cultivation area. The YI defined in this deliverable is the ratio between crop yield under marginal conditions and the yield attainable under non limiting conditions. The latter are identified as the maximum expected yield for the specific crop when grown in favorable soils within the same area. This approach enables a direct comparison of productivity in marginal lands with a realistic local benchmark representing the best agronomic conditions. The YI provides insights into the limitations imposed by marginal soils and serves as a normalized metric for evaluating performance across systems within the same geographic and climatic context. In line with the reference study, the interpretative limits of the YI are maintained: a value of 0 represents zero productivity in marginal lands, while a value of 1 signifies yield equivalent to that under favorable conditions.

#### 2.2.2.2. Land Equivalent Ratio (LER)

The **Land Equivalent Ratio** is an agroecological indicator used to compare the productivity of intercropping systems with that of monocropping systems. It measures the efficiency of land use in intercropping by assessing whether growing multiple crops together yields more than growing them separately on the same amount of land (Mead & Willey, 1980).

Where LER represents the sum of ratios for each crop. Within this calculation an LER value of 1 indicates that there is no yield advantage of the intercrop compared to the monocrop, while a LER of 1.1 indicates a 10% yield advantage. Given that the MIDAS project includes agroforestry systems, individual ratios were calculated to evaluate their performance. These ratios were determined by dividing the total woody biomass production (Mg $ha^{-1}$) from the agroforestry case study by the total biomass expected to be produced in a conventional forestry system (Rezgui et al., 2024).

# Outlook

This Deliverable present a framework of farm-scale environmental indicators developed under the MIDAS project to evaluate the sustainability of innovative farming systems. Designed within the DPSIR model, these indicators address critical dimensions such as land use, resource efficiency, biodiversity and productivity.

However, it is important to note that not all indicators will be universally applied to every cropping system. A tailored approach will be adopted, selecting only the most relevant indicators to capture the specific impacts and characteristics of each case study. This tailored approach ensures that the MIDAS project delivers precise and impactful assessments, supporting the transition to more sustainable and resilient farming systems

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