# Searching for suitable biological indicators to monitor the effects of plant protection product residues in agricultural soils

## Background and Introduction

In agriculture, plant protection products (PPPs) are widely applied to protect crops from pests and guarantee high productivity. Before entering the market, PPPs are subject to an authorization procedure, based on standard tests, to prove that they do not cause negative effects on non-target organisms. However, natural ecosystems are complex and the behavior and impact of a chemical in the environment might not be adequately represented in the standard conditions of the prospective evaluation. While some PPPs degrade rapidly after application, other PPPs can persist as residues in the ecosystem. In addition, in agricultural systems, not one but a mixture of several PPPs is often found. As such, non-target organisms and their natural communities, which provide important services to the ecosystem, can be exposed to multiple PPP residues and may experience undesired adverse effects, which are often difficult to predict. Monitoring the actual occurrence, persistence and effects of PPP residues in the environment can be useful to complement current approaches.

### The Action Plan and the ConSoil project – a long-term monitoring for PPP residues in agricultural soils

To reduce the risks of PPPs and promote their sustainable use, the Federal Council approved in 2017 an Action Plan for PPPs (AP-PPP). Within the AP-PPP measure 6.3.3.7 aims to develop a monitoring of PPP residues to evaluate their effects on long-term soil fertility.

Under measure 6.3.3.7, the ConSoil project was created to propose a concept for assessing the long-term risk of PPP residues on soil fertility. One objective of the ConSoil project is to develop biological indicators for assessing the effects of PPP residues. Indicator tools can be both laboratory tests, with soil samples from the field, as well as direct ecological field investigations. In both cases, measured effects can be structural (population size, community composition) or functional by measuring the activities performed by organisms (e.g., organic matter decomposition).

In order to choose suitable biological indicators, the following questions need to be answered: 1) what is soil fertility? And 2) which soil organisms contribute (the most) to the ecological soil functions important for soil fertility?

## 1) What is soil fertility?

The definition of soil fertility is taken from the Swiss Ordinance related to Impacts on Soils of 1st July 1998 and is summarized in Box 1.

> ***Box 1:*** *A fertile soil presents an active biological community, as well as a structure, composition and thickness typical for its location, and an intact decomposition capacity. Moreover, plants can grow and develop undisturbed.*

In other terms, the following ecological soil functions need to be preserved:

- Production function: ability of the soil to produce agricultural goods
- Regulating function: ability of the soil to store, regulate and filter water, nutrients, and pollutants
- Habitat function: ability of the soil to provide the necessary conditions and resources for organisms and to contribute to the maintenance of the diversity of ecosystems, species and their genetic diversity.

## 2) Which soil organisms contribute to soil fertility?

Soils are inhabited by different organisms, such as microorganisms (e.g., fungi, bacteria), mesofauna (e.g., soil microarthropods), macrofauna (e.g., earthworms, isopods) as well as plants, which interact together in heavily connected networks. Soil organisms are involved in several ecological processes which in turn provide ecological soil functions. To protect long term soil fertility, the organisms providing the three ecological soil

functions supporting soil fertility (point 1, see above) need to be protected.

In order to identify specific organisms, which are important actors to protect soil fertility, the ConSoil team produced a technical report (Dell'Ambrogio et al. 2023), where links between different actors and respective ecological soil functions and processes are compiled, based on the current scientific knowledge, and summarized in the "Actors to Ecological Soil Functions" (AESF) table.

## The AESF table

In the scientific literature, the role of soil organisms in ecosystem functioning is described using different classifications under different contexts and goals. Therefore, the available information had to be screened for relevance and integrated into a common classification, which was based on the concept of ecosystem services (see Box 2).

> ***Box 2:*** *Ecosystem services are defined as the benefits that humans receive from the functioning of the ecosystem and are used as an important communication tool for stakeholders. The most recent classification is the Common International Classification of Ecosystem Services (CICES - https://cices.eu/), where ecosystem services can be classified into several levels of detail in a hierarchical structure. The Section level provides the lowest detail, while the Class level provides the highest detail.*

To produce the AESF table, the following steps (summarized in Figure 1) were applied:

- **Step 1:** Integrating soil fertility into the CICES concept: linking ecological soil functions to ecosystem services (Section level)
- **Step 2[1]:** Screening of ecosystem services (Class level) for relevance to soil fertility
- **Step 3[2]:** Integrating information from scientific literature into CICES concept (Class level)
- **Step 4[2]:** Adding the concept of Processes to ecosystem service Classes
- **Step 5[2]:** Attributing Actors to Processes

## Conclusion and Outlook

While the attribution of Actors to Processes and ecosystem services is based on scientific knowledge, the choice of the ecosystem services to be protected has to be made together with decision makers. For this purpose, ecosystem service Classes will be ranked for their importance to soil fertility, using the results of a questionnaire submitted to stakeholders and experts in the field of agriculture (policy, academia, land-users). Actors will be prioritized, based on the number of connections they share with the ranked ecosystem services and the selection of most suitable biological indicators will as best as possible cover priority Actors for soil fertility.

[1] The CICES has a broad context, therefore only Classes considered relevant for the ConSoil project were selected.

[2] Steps 3 to 5 are based on the scientific literature: Processes reflect the direct role played by Actors, which contributes to the ecosystem service Classes. Although the relative contribution of each Actor is hard to quantify, the compiled information provides an overview of the qualitative links between Actors and Processes

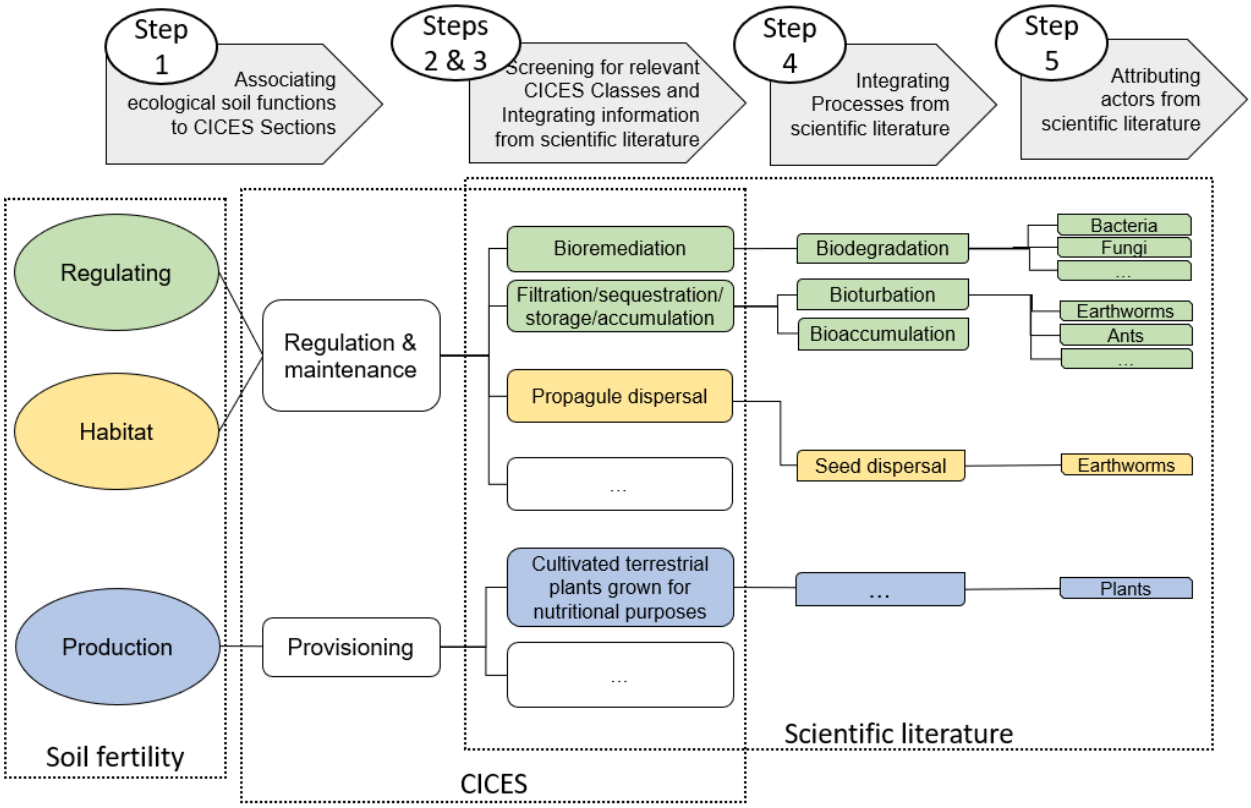


*Fig. 1: Stepwise procedure applied for the production of the AESF table, illustrating the links between ecological soil functions, ecosystem services (ES), processes, and actors (i.e. soil organisms), with some examples. Ecological soil functions are color coded, blue = production function, yellow = habitat function, green = regulating function. ES are defined based on the Common International Classification of Ecosystem Services (CICES - https://cices.eu/). Processes and their link with Actors are based on scientific literature. For the detailed description of the procedure, see Dell'Ambrogio et al. 2023.*

## Glossary

| | |
|---|---|
| Actors: | Broader term to define different ecological and taxonomical groups of soil organisms, e.g., plants, earthworms, bacteria. |
| Ecological soil functions: | Result from the normal functioning of the soil ecosystem which, in the context of soil fertility under the Swiss National Soil Strategy, correspond to the production, regulating and habitat function. |
| Ecological processes: | Actions and interactions of soil organisms with their environment contributing to ecological soil functions. |

- For more information about the selection of bioindicators, see: Dell'Ambrogio G., Renaud M., Campiche, S., Marti-Roura, M. Ferrari, B. (2023). *Selection of a bioindicator toolbox for monitoring effects of plant protection products residues Part 1 – Linking ecological soil functions and soil organisms*. Swiss Centre for Applied Ecotoxicology, Dübendorf and Lausanne, Switzerland.
- Contact: Mathieu Renaud, Ecotox Centre
- About ConSoil Project: https://ecotoxcentre.ch/projects/soil-ecotoxicology/monitoring-concept-for-plant-protection-products-in-soils

*Table 1: Summary of the AESF table showing the resulting links between Actors (columns) and ecosystem service Classes (rows). Numbers indicate the number of Processes performed by Actors, i.e., the number of occurrences of the Actor, for each ecosystem service Classes. Ecological soil functions are color coded, blue = production function, yellow = habitat function, green = regulating function.*

| | Earthworms | Bacteria | Plants | Fungi | Enchytraeid | Collembola | Mycorrhiza | Ants | Nematodes | Acari | Protozoa | Coleoptera | Isopods | Diplopoda | Microalgae | Gastropods | Insects | Archaea | Spiders | Viruses |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivated terrestrial plants, fibres or other materials from cultivated plants grown for nutritional purposes, for direct use or processing, or as a source of energy | | | 1 | | | | | | | | | | | | | | | | | |
| Seeds, spores and other plant materials collected for maintaining or establishing a population | | | 1 | | | | | | | | | | | | | | | | | |
| Propagule dispersal | 2 | | | | 1 | 1 | | | 1 | 1 | | 1 | 1 | 1 | | | | | | |
| Pollination | | 1 | | | | | 1 | | | | | | | | | | | | | |
| Maintaining nursery populations and habitats (Including gene pool protection) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Bioremediation | 1 | 1 | 1 | 1 | | 1 | 1 | | 1 | | | | | | | | | | | |
| Filtration/sequestration/storage/accumulation of toxic substances | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | | | 1 | | | | 1 | | | | |
| Control of erosion rates | 2 | 1 | 3 | 1 | 2 | 1 | 1 | 2 | 2 | | | | | | 1 | | | | | |
| Hydrological cycle and water flow regulation | 4 | 1 | 3 | 1 | 4 | 2 | 1 | 3 | 3 | 1 | | | 1 | 1 | 1 | | | | | |
| Pest and disease control | 3 | 6 | 3 | 6 | 1 | 3 | 2 | 1 | 1 | 2 | 4 | | | | | | 2 | 1 | 1 | 1 |
| Weathering processes | | 1 | 1 | 1 | | | 1 | | | | | | | | | | | | | |
| Decomposition and fixing processes | 5 | 4 | 4 | 4 | 5 | 4 | 2 | 2 | 2 | 3 | 2 | | 1 | 1 | 1 | | | 1 | | |
| Regulation of the chemical condition of freshwaters | 1 | 2 | 2 | *2* | 1 | 1 | 2 | 1 | 1 | 1 | | 1 | | | | 1 | | | | |