SPIN-FERT: INTEGRATING TOOLBOX FOR SMART AND RAPID SOIL HEALTH ASSESSMENT

How robotics, biosensors and a new holistic quality index are giving European growers, manufacturers and policy makers an evidence-based path to healthier soils

The "One Health" imperative for European soils

Soil is a living, non-renewable resource under threat from degradation, erosion and biodiversity loss driven by intensive agriculture. The EU's Horizon Europe "Mission Soil" initiative addresses this within a "One Health" framework linking soil vitality to human well-being. SPIN-FERT project responds directly to this challenge, developing various tools that can accelerate the shift to healthy soils, as they are mainly addressing biological soil fertility.

Robotics in the field: Automating biological soil analysis

SPIN-FERT is developing a dual-robot system, developed by OTH, that automates biological soil analysis at field scale. A Field Robot collects GPS-tagged soil samples across the field, while an Analytic Robot prepares soil-water suspensions and captures 3D microscopic video so no organisms are missed. AI, using diverse algorithms, identifies and counts bacteria, fungi and nematodes (distinguishing harmful from beneficial species). The tool can thus directly determine an overall level of soil biodiversity that lets users fine-tune soil management to improve their soil's biological fertility.

Advanced biosensors: Real-time tracking of microbial biostimulants

To track microbial biostimulants in soil, SPIN-FERT is validating two devices based on an innovative biosensor – a DNA aptamer selected on a common bacterial species, Bacillus subtilis, known for its plant biostimulation features.

The devices are exploiting a shift in resonance frequency after bacterial binding (QCM method) or a microfluidic analysis of Surface Acoustic Wave carried on with a Lab-on-Chip developed by the spin-off INTA. The latter method allowed to reach a detection limit of 10^3 U/mL for B. subtilis – three orders of magnitude more sensitive than the QCM methods, suitable for field analyses.

The device can thus be used to monitor the presence of the microbial biostimulant, which can help farmers defining when it is necessary to apply it, but also can be used by biostimulant producers to refine the application method and provide data during the registration process necessary to obtain authorization for marketing the product.

The Seed-Resp System: A rapid bioassay for biostimulants testing

Seed-Resp, adapted from the MicroResp™ platform, has been developed by SPIN-FERT to provide a quick bioassay of seed vigour which can be used to validate the suitability of organic biostimulants to promote plant growth, a feature required to register them for marketing.

The system measures respiration of seeds positioned inside a 96-well plate containing a color indicator turning from purple to yellow, which can, within minutes after the seeds imbibition, easily quantify the CO_2 produced by measuring absorbance at 570 nm.

Across various plant species (Lepidium sativum, lettuce and tomato), the system was able to detect stress from NaCl and showed a significant correlation between the absorbance and root elongation – validating CO_2 output as a proxy for seeds' vigor.

Electronic nose: Capturing the scent of soil vitality

A non-invasive, portable electronic nose estimates microbial activity measuring the microbial-produced Volatile Organic Compounds (mVOCs) without disturbing the soil.

Different microbial species emit unique mVOC blends depending on soil health status. Thus, analyzing soil-emitted mVOC signatures provides information on the below ground microbial activity and diversity linking specific microbial traits to soil health. The system will allow to monitor the presence of plant-beneficial and pathogenic microorganisms in the soil, providing key information about the impact of soil management practices on soil health, useful for farmers, manufacturers and policy makers.

The Soil Holistic Quality Index (SHQI): From data to decisions

Data of soil physical, chemical and biological parameters converge to

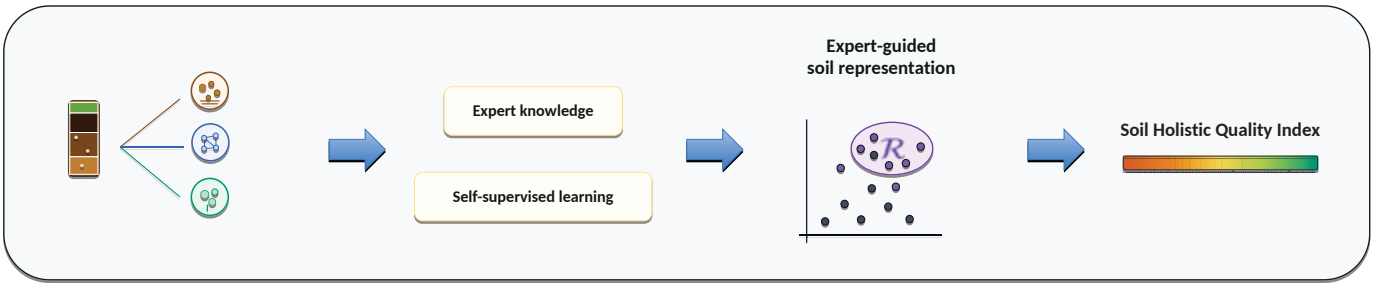


Figure 1: The methodological approach used to develop the Soil Holistic Quality System, combining expert knowledge and machine learning

define the Soil Holistic Quality Index (SHQI), an interpretable and data-driven framework for soil quality assessment.

Using expert knowledge on soil agronomic suitability and self-supervised machine learning algorithms, the framework estimates how closely a soil sample resembles optimal soil conditions, thereby quantifying soil quality on a continuous scale from 0 to 100 and identifying non-optimal indicators (Figure 1).

This multivariate approach is particularly important, because agronomic soil quality is shaped by complex interactions among soil texture, acidity, nutrient availability, organic matter, and biological activity.

The tool is developed to support farmers, land managers and policy makers by translating complex soil measurements into reliable and meaningful soil quality estimates, ensuring agronomic interpretability and helping to monitor soil health and evaluate the impact of management practices over time.

The SHQI is thus aligned with the needs of the EU Soil Monitoring Law and its inclusion within an open access platform SoilHive, connecting SHQI with the territory is aimed to favor the implementation of the EU Directive by the Member States.

An integrated ecosystem of tools with EU policy impact

Together, these innovations form an integrated ecosystem that provides to the agricultural stakeholders, farmers, advisors, manufacturers and policy makers, a route to care for soil health: fostering the correct use of organic and microbial biostimulants, and monitoring the quality of the soil and the impact of practices and policies on it. The effort of SPIN-FERT is to securing a more resilient, evidence-based future for European horticulture.

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