SOIL & PLANT MONITORING: MONITORING-SUPPORTED DECISION-MAKING FOR EFFECTIVE NATURE-BASED SOLUTIONS

Summary

Climate change, soil degradation, and water scarcity are placing growing pressure on European agriculture. While nature-based solutions such as cover cropping, reduced tillage, and organic soil regeneration are increasingly promoted, farmers often struggle to detect early signs of soil stress and crop health problems in time to act.

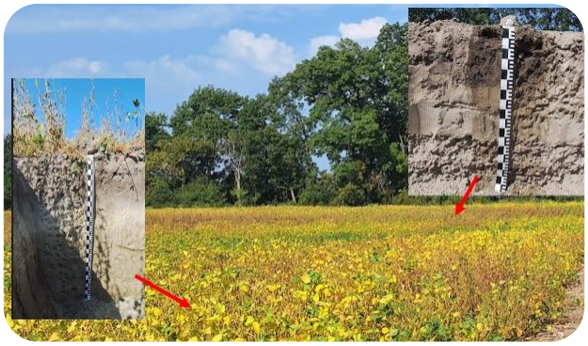
The **Soil & Plant Monitoring approach** within the trans4num framework addresses this by making soil and crop conditions measurable, visible, and understandable. Through field observations, monitoring tools, and data-driven methods, farmers and advisors can better understand soil-plant processes, optimise resource use, and apply nature-based solutions more effectively.

The need

Many soil degradation processes remain invisible until crop performance has already declined. Compaction, reduced water retention, nutrient imbalance, and biological degradation develop gradually and are difficult to detect without systematic monitoring. Climate extremes (prolonged drought and irregular rainfall) place additional stress on both soils and crops.

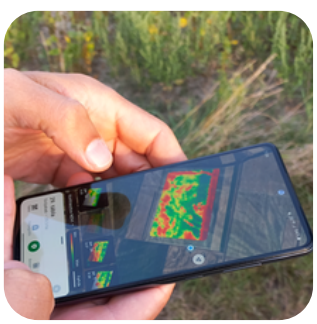
Relying on visual observation alone leads to delayed interventions and inefficient use of water, fertilisers, and other inputs. Natural soil variability within a single field adds further complexity, as different layers and zones respond differently to tillage, nutrient applications, and weather events.

There is therefore a growing need for practical, field-level monitoring that enables early decision-making and helps farmers adapt nature-based solutions to local conditions, verifying the outcomes of agricultural trials while providing continuous guidance for nutrient management and adaptive field decisions.



The benefits

- **Early stress detection**: Monitoring allows farmers to identify soil and crop stress before severe damage develops.
- **Improved water management**: Soil moisture monitoring supports more efficient irrigation and better water-retention strategies.
- **Reduced input use**: Better understanding of soil and plant conditions can decrease unnecessary fertiliser and water application.
- **Improved nutrient management**: Real-time nutrient monitoring supports site-specific and crop-adapted fertilisation decisions.
- **Support for nature-based solutions**: Monitoring strengthens the effectiveness of nature-based and soil-regeneration practices.
- **Better understanding of soil variability**: Soil profile investigations and spatial analyses improve precision management.
- **Climate resilience**: Healthy soils and informed management improve the resilience of agricultural systems against drought and extreme weather events.
- **Data-driven decision-making**: Combining field observations with digital technologies enables more accurate and adaptive farm management.



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trans4num solution

The **Soil & Plant Monitoring approach** combines field observations with digital and sensor-based tools to support sustainable soil management and climate adaptation. It integrates soil analyses, plant monitoring, and spatial assessment to better understand soil–plant interactions and strengthen the implementation of nature-based solutions.

Soil Monitoring

Key indicators, like moisture, temperature, structure, and organic matter, provide essential information about soil health, water availability, compaction, and erosion risks. Soil profile investigations go deeper, revealing stratification, root-zone conditions, and water movement processes that are invisible from the surface.

Continuous nutrient assessment allows farmers to understand nutrient availability and balance, adapting fertilisation to actual field conditions rather than fixed schedules. Additional methods such as soil respiration and CO_2 measurements offer further insight into biological activity, supporting more regenerative soil management.

Plant Monitoring

Plant monitoring tracks crop vitality, leaf colour, biomass, and vegetation indices to detect early stress (from drought, nutrient deficiency, or soil degradation) before yield losses occur. Leaf analyses assess nutrient uptake and crop physiology, while drone-based and multispectral imaging reveal spatial variability and differences in crop performance across the field.

Aligned with crop development stages and field treatments, plant monitoring data provides a real-time, site-specific basis for optimising nutrient applications and reducing unnecessary inputs.

Supporting Nature-Based Solutions

Monitoring results directly support nature-based solutions such as cover cropping, mulching, compost application, and reduced tillage. Understanding soil variability, nutrient dynamics, and soil–plant interactions allows farmers to select and adapt nature-based solutions precisely. For example, choosing cover crop species suited to specific soil structure and moisture conditions.

Monitoring thus becomes not only a performance-tracking tool, but a key element in implementing and optimising climate-resilient, nature-based agricultural management.

What were the challenges / limitations in the implementation process?

- **Timing and operational capacity**: Suitable windows for field operations are narrowing and becoming less predictable; Farmers may lack the capacity to act at the right moment, even when data indicate optimal conditions
- **Data availability and interpretation**: Fast access to reliable, real-time data is essential but not always achievable; Converting large data volumes into practical management guidance remains complex
- **Data integration and compatibility**: Combining sensors, drone imagery, lab analyses, and field observations is technically demanding; Differences in formats, scales, and methods limit the use of integrated monitoring systems in practice

What kind of resources do you need to implement the proposed solution?

- **Monitoring tools and methods**: Soil and leaf analyses, in-situ sensors, drone and satellite observations; Digital decision-support tools to interpret soil variability, crop conditions and ecosystem processes
- **Key practices supported by monitoring**: Cover cropping, reduced tillage, mulching, organic amendments, site-specific nutrient management
- **Advisory and knowledge inputs**: Farmer experience and advisory support for data interpretation; Adaptation of regenerative practices to local soil conditions and crop requirements

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Practical recommendations for users

- Select nature-based solutions based on local soil and crop conditions. For example, matching cover crop species to soil structure, moisture, and nutrient status
- Apply continuous soil and plant monitoring throughout the growing season, as regenerative management requires both spatial and temporal precision
- Align nutrient applications with crop phenological stage and actual demand to improve efficiency and minimise losses
- Use soil and leaf analyses before peak uptake periods to inform fertilisation, organic amendments and foliar applications
- Adapt tillage timing and intensity to actual soil conditions to improve structure, water management and nutrient availability while avoiding compaction
- Combine drone-based monitoring, spatial assessment and field observations to understand field variability and support precise regenerative management

Next steps & scaling

- Closer integration of monitoring into the practical implementation of nature-based solutions
- Faster real-time data access and improved decision-support tools to help farmers better time and adapt regenerative practices
- Stronger knowledge transfer, demonstration activities and advisory networks to support wider adoption
- More site-specific management (cover crop selection, nutrient management, precision tillage) to build long-term resilience and sustainability

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Learn more about the project at https://trans4num.eu/en/

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