



Root2Res

Root phenotyping and genetic improvement for rotational crops resilient to environmental change

D7.5 – Policy Brief 2

Plant Roots in Soil Health

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D7.5 includes the second Root2Res policy brief, focussed on plant roots in soil health. It explains why understanding roots is crucial for soil health, and why targeted investment in root trait research, along with supportive policies, is vital.

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1. Process and next steps

Like the first Root2Res policy brief¹, the second policy brief was developed through a participatory process. We consulted the Root2Res policy officer, the Root2Res Stakeholder Advisory board and the Root2Res Consortium to determine the most suitable topics. Since soil health is currently a policy priority, the policy brief aims to:

- make policy makers aware of the importance of roots in soil health, and
- highlight the need for targeted investment and policies that support living root systems.

In addition to this deliverable, the policy brief will be published in a format attractive to policy makers². It will also be disseminated through established Root2Res channels as well as partner channels and sent to relevant policy organisations. We will also assess the need to translate it into other project languages for use at the national policy level.

2. Policy brief

Plant Roots in Soil Health

Key messages

- Soil health is critical for sustainable agriculture, climate resilience, food security and biodiversity.
- Healthy roots play a key role in soil carbon storage, water retention, structure, resilience and biodiversity — yet they are often overlooked in policy and research.
- We need targeted investment in root trait research, breeding, and field trials to unlock their full potential.
- Support policies are needed that reward living root systems — through the CAP, national soil strategies and new incentives for farmers.

Introduction

Soil health — commonly defined as the continued capacity of soil to function as a living ecosystem that sustains plants, animals, and humans — is fundamental to sustainable agriculture, climate resilience, and ecosystem services [1,2]. The European

¹ George, T., Cohan, J.-P., Kemper, L., & White, C. (2024). Roots in policy: How to encourage breeding for root-related traits and more resilient crops. Zenodo. <https://doi.org/10.5281/zenodo.11189796>

² Gallmann, N., Cohan, J.P., George, T., Kemper, L., Baxter, C., Dupuy, L., Postma, J. and Vetterlein, D. (2025). Plant Roots in Soil Health. Zenodo. <http://doi.org/10.5281/zenodo.16911590>

Union's (EU) Soil Strategy for 2030 underscores the urgency of preserving soil functions, as they are vital for food security, biodiversity, and climate change mitigation [3]. However, inappropriate agricultural practices and climate change have led to soil degradation, declining levels of soil organic carbon, and loss of plant, soil fauna and microbial diversity [4, 5, 6].

Several EU initiatives emphasise the importance of soil health, including the EU Mission: A Soil Deal for Europe, the Soil Monitoring Law, the Nature Restoration Law and the Common Agricultural Policy (CAP). Climate-smart strategies such as carbon farming also recognise the role of soils in climate change mitigation through carbon sequestration and improved management practices.

In agricultural soils, plant roots are a key driver of soil processes and overall soil health, yet they have been largely overlooked in research. Plant roots transfer carbon into the soil through exudation and decomposition, and play a crucial role in shaping soil structure, nutrient cycling, water retention, microbial interactions and disease suppression. These functions are essential for maintaining healthy, productive soils [7].

This policy brief reviews the current scientific understanding of roots and soil health, highlights key knowledge gaps and explores policy opportunities to unlock the potential of root systems in tackling soil-related challenges.

Key scientific insights on root–soil interactions

Soil carbon

Roots play a key role in the soil carbon cycle, an increasingly important aspect of climate mitigation [8]. Plants allocate up to 60% of their fixed carbon belowground, bringing it in the soil through root biomass and crop residues. Unlike shoot residues, roots place carbon deeper into the soil, without requiring transport by soil fauna. Additionally, root exudates — carbon compounds released into the soil by roots — support microbial communities whose necromass contributes significantly to the cycling and stabilisation of soil carbon [9]. However, our understanding of which specific root traits most effectively support these processes is limited and further research is needed to fully uncover the potential of roots in enhancing soil carbon storage, while also considering potential trade-offs between allocating carbon to roots versus aboveground biomass.

Soil structure

Roots and their carbon inputs contribute to the physical arrangement of soil particles, known as soil structure, both directly by creating biopores and indirectly by promoting the formation of soil organic matter. Both pathways, in turn, play a crucial role in improving soil stability and fertility. Root exudates contribute to this process by nourishing soil microbes and promoting the growth of beneficial fungi and bacteria [10,11].

The physical influence of roots is particularly significant [12]. Root systems increase cohesion and overall mechanical strength of soil, reducing the risk of erosion. They promote aggregate formation that enhance structural integrity, and they can penetrate compacted or hardened soil layers, creating pore spaces and improving aeration and drainage. However, soil compaction remains a widespread and serious

issue in modern agriculture, restricting root development and compromising many of the soil functions described above [13]. Plant species have varying abilities to overcome compacted layers. Identifying root traits that most effectively support structural improvements remains a key research need [14,15,16].

Water retention

Good soil structure, supported by living roots, enables water infiltration, storage and retention, making it available to plants and other living organisms in the soil while also reducing runoff and erosion. Deep roots enable plants to access water stored in the lower layers of the soil, improving their resilience to drought and potentially making some moisture accessible to nearby species with shallower roots [17]. In contrast, shallow and fibrous roots enhance surface soil porosity, promoting water infiltration and helping soils recover from waterlogging through improved drainage and aeration.

More insights are needed to guide root trait selection and management to optimise drought resistance and mitigate excess water in agricultural systems.

Nutrient cycling and uptake efficiency

Crop root systems play a vital role in nutrient cycling and mitigating environmental impacts from nutrient loss. Nitrogen is particularly significant because it is widely used in agriculture and is highly susceptible to leaching due to its solubility. Deep-rooted cereal crops can access nitrogen that has leached into deeper soil layers, increasing nitrogen uptake and reducing environmental losses [18,19]. Also, root system plasticity, i.e., their ability to adapt to current environmental conditions, may offer promising opportunities to improve the efficiency of fertiliser, e.g., reducing phosphorus loss to the soil. Further research is needed to identify which root traits most effectively enhance nutrient acquisition and efficiency, and how these traits can be bred or managed within diverse cropping system.

Microbiome

Plants actively shape the surrounding soil environment, known as the rhizosphere. The composition of the soil microbiome directly impacts soil health. While some microbes suppress pathogens, others can promote disease under certain conditions. A diverse and balanced microbial community supports plant resilience, nutrient cycling and long-term soil fertility. Genotype specific root exudation patterns can influence the surrounding microbiome, which may help mitigate challenging periods, such as drought. Such adaptive responses demonstrate the dynamic role of roots in mediating interactions between soil, plants and microbes. Yet the soil–root–microbiome interface likely holds many unknown functions, making it a crucial research focus for sustainable agriculture and soil health.

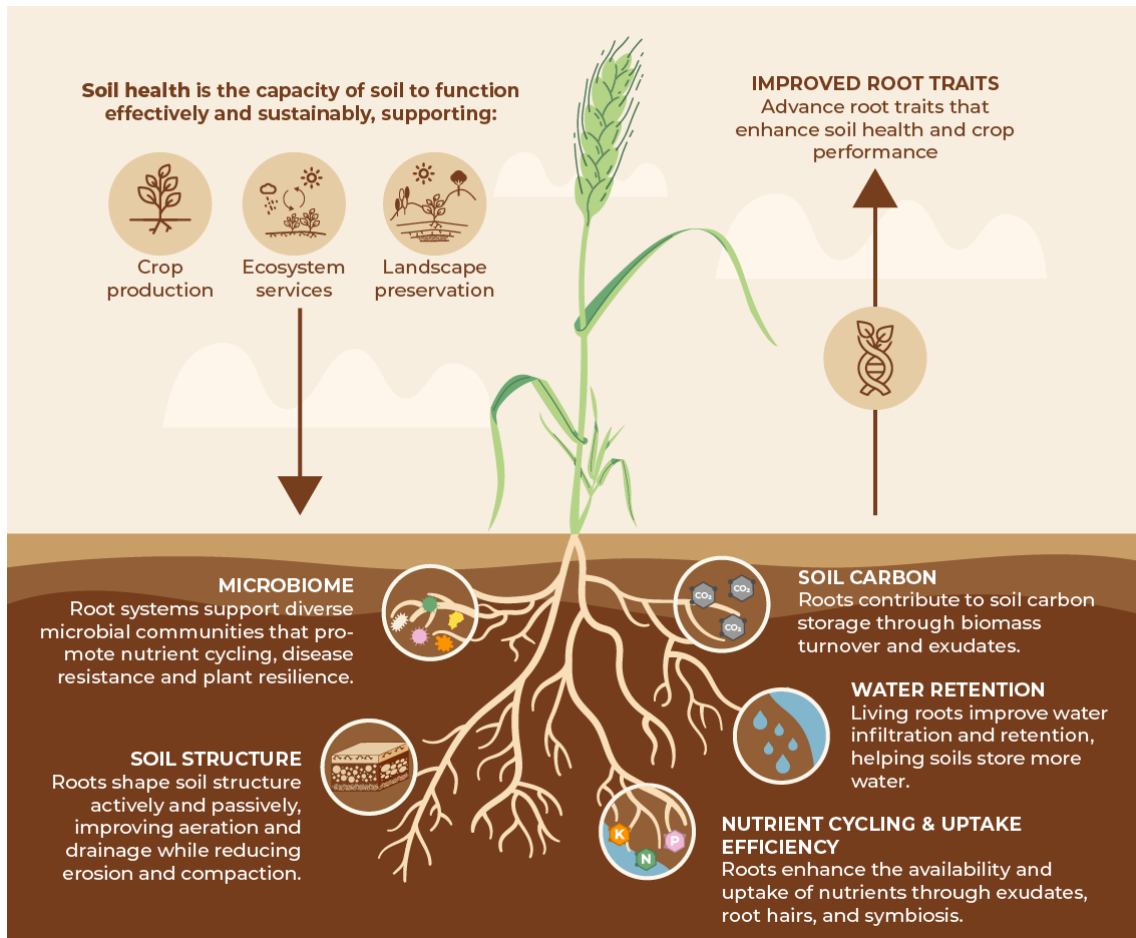


Figure 1. The importance of root traits in increasing resilience and mitigating environmental stresses.

Conclusions and policy recommendations

Living roots play a vital role in promoting soil health. Using nature-based solutions, including a combination of cash crops and multi-service plants such as cover crops, green manure and inter-cropping, ensures year-round living root systems. This boosts short-term productivity while providing a long-term investment in ecosystem sustainability.

Despite significant advances in understanding root biology, substantial knowledge gaps remain in applying this knowledge to concrete, evidence-based guidelines, policy frameworks and agricultural practices that optimise both productivity and ecosystem services, such as soil health.

Advancing our understanding of the soil-root-microbiome interface can transform agriculture, enhancing productivity, resilience, and sustainability. Investing in this research is essential to drive science-based innovation in soil management and climate action.

Specifically, we recommend that you:

1. **Maintain and strengthen EU Framework Programme funding** for collaborative, public-good research. Support pan-European consortia and living labs to enable robust, system-level assessments of root traits and their contributions to climate-smart, regenerative agriculture.
2. **Increase investment in interdisciplinary research** on root traits, root plasticity, and their influence on soil functions across different farming systems.
3. **Expand and/or strengthen below-ground phenotyping networks** to lower costs and improve research efficiency, e.g., networks like “PHENOME EMPHASIS” that focus on roots.
4. **Support long-term field studies** to evaluate root systems’ effects on soil structure, carbon storage, water regulation and nutrient use efficiency. These studies should include both controlled trials and on-farm research.
5. **Strengthen on-farm research** to help growers understand which management practices (e.g. reduced tillage, cover crops) enhance root system development, how these practices interact with soil conditions, and how benefits can be quantified and integrated into existing production systems.
6. **Improve breeding programmes** to select beneficial root traits, including root-microbe interactions. This could involve incorporating root traits into Value for Cultivation and Use assessments and expanding trait evaluation to include non-cash crops (e.g., cover crops and intercrops), which contribute to year-round root presence and provide system-wide benefits.
7. **Include root-centric strategies** in national and regional policies for soil health, climate resilience and sustainable agriculture — recognising root systems as drivers of change.
8. **Create incentives to maintain living roots in the soil year-round** through practices like cover cropping, including perennials and minimising fallow periods, as part of regenerative and climate-smart agricultural policies.

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