A HAIR'S BREADTH

Rooting out sustainable soils and food production

Roots are active architects of the soil around them – a zone known as the rhizosphere. To understand how plants manipulate the rhizosphere, Professor Paul Hallett and colleagues used novel imaging techniques, physical and chemical analyses to reveal the complex interactions between roots and soil. They suggest that crop breeders could tap into root traits to improve nutrient uptake, soil health, and water holding capacity. Crops that promote a healthy rhizosphere could help degraded soils recover and ensure healthy ones stay that way.

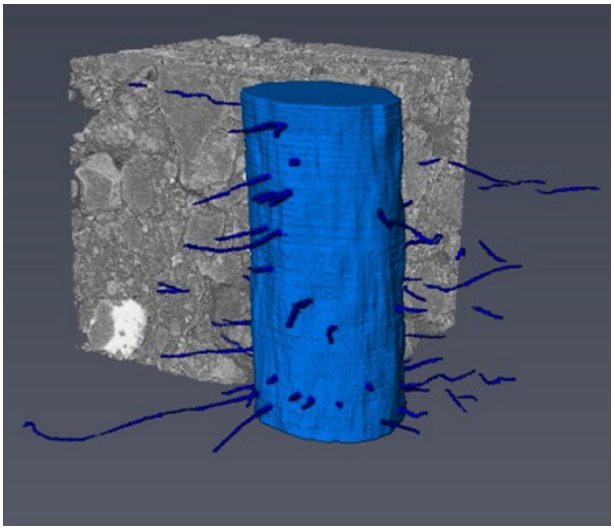
Introduction

When we think about the factors affecting plant health and growth, it's easy to focus above ground and forget about what's going on in the soil. But roots are far more than just a physical necessity, helping hold up plants and take up water. They also engineer the physical, biological and chemical properties of the soil around thetm. This means that roots have a big influence on soil health and can affect natural soil services, such as absorbing floodwater and storing carbon.

"The rhizosphere is this very thin zone of soil between the plant and the water-soil environment, and the plants manipulate it considerably … to capture nutrients, to capture water and ease their root growth through the soil", said Hallett.

But this underground world is extremely difficult to study, so how plant roots form the rhizosphere and influence plant productivity and soil health is still poorly understood. A team of researchers led by Paul Hallett (University of Aberdeen) set out to better understand how plant traits affect the root-soil interface and the vital ecosystem services it provides.

Previous research by Hallett and his team found that root hairs physically engineer the soil of the rhizosphere. Now, high-tech imaging techniques mean *"we are ablwe to see through the soil"*, he said, allowing the team to visualise the interactions between plant roots and the surrounding soil in remarkable detail.



The 3D structure of the rhizosphere, photographed using the Diamond Light source, the highest resolution X-ray CT scanner in the UK. High-resolution images show how root hairs manipulate rhizosphere soil structure.

THE BASICS

Plant roots are important for anchoring the plant to the ground, but they are also a corner stone of **plant health** – they control nutrient and water uptake, and influence carbon emissions and drought-tolerance.

Roots are **architects** of soil structure, and to do this they release a variety of compounds into the soil that help them grow and absorb water and nutrients. They also play an important role in the health of the surrounding soil, known as the **rhizosphere.**

The surface of roots are often covered with millions of **tiny hairs**, which increase the surface area across which the plant can absorb nutrients and secrete chemicals.

KEY FINDINGS

- The researchers took the first ever **sub-micron resolution** images of plant roots manipulating **soil structure.**
- Plant roots exude **acids and gelling compounds** that help the plant absorb water, phosphorous and other nutrients.
- Root hairs create pores that increase the soil's **capacity to hold water.**

Methodology
The team grew strains of barley and maize that were nearly genetically identical but differed in the quantity of root hairs – hairless, normal, and very hairy. In field and greenhouse experiments, they measured how fast the plants grew, monitored their water use and nutrient uptake. They also measured physical characteristics of the soil and collected samples of the compounds exuded by plant roots.

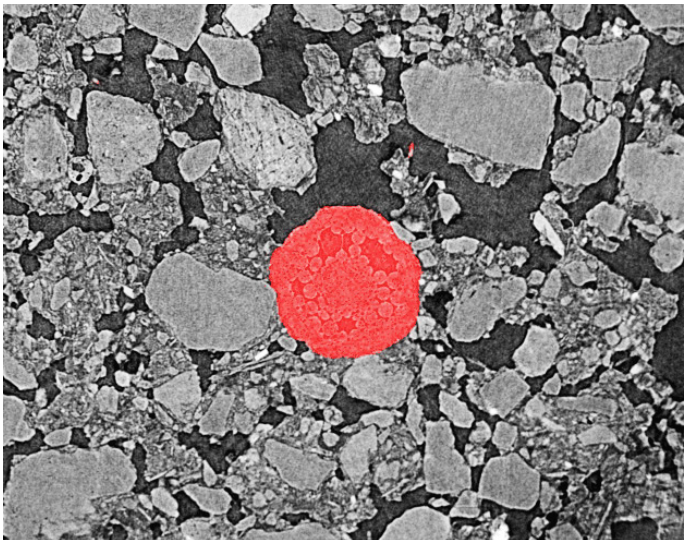
Using a high-resolution non-invasive imaging technique known as synchrotron X-ray CT, the researchers created 3D images of the rhizosphere and used computer modelling to predict how different root traits would affect the plant's ability to extract nutrients and water from the soil.

Results
Using a novel imaging method, Hallett and colleagues produced the first ever sub-micron resolution observations of plant roots manipulating the structure of the soil to improve their nutrient uptake. They found that plant roots have a significant effect on plant water absorption from the soil by creating a complex underground 3D structure.

In particular, they found that root hairs create air gaps or 'pores' in the soil, both through their physical growth and the compounds they release. Hairier roots and those with longer root hairs had a greater physical effect on the soil. They formed large pores where the soil had been compressed by the growing root, increasing the amount of water the soil could hold and stabilising it against extreme weather.

The composition of chemicals released by the root also affected the capacity of the soil to hold water. These compounds fell into two broad categories – organic acids, which are thought to break down soil, releasing nutrients and paving the way for new roots to grow, and polysaccharides that attract water and have a gelling effect that also creates space to make way for root hair growth.

Hallett says that the next step is to look in detail at the genetics of the plants to understand which genes control these root characteristics.



A cross-section of a root hair and the surrounding soil. Computer modelling revealed how the structure of the rhizosphere soil influences nutrient and water movement.

BROADER IMPLICATIONS

- The rhizosphere is an un-tapped resource for plant breeders, who could see substantial improvements in both plant and soil health, with knock-on effects for **crop yield**.
- Root traits could also be selected that make plants better at absorbing **key nutrients** like phosphorous from the soil, allowing farmers to use fewer fertilisers and improving the quality of the soil.
- Breeding for better root hair characteristics could even help farmers improve **degraded soils** with specially adapted rhizosphere-friendly crops.

"There's a chance to not only focus on making the plant better, but through the plant – make the soil better"
- Paul Hallettt

Contact Details: Professor Paul Hallett
(paul.Hallettt@abdn.ac.uk)

References

Koebernick, N., Daly, K. R., Keyes, S. D., George, T. S., Brown, L. K., Raffan, A., ... & Hallettt, P. D. (2017)' to 'Koebernick, N., Daly, K. R., Keyes, S. D., George, T. S., Brown, L. K., Raffan, A., ... & Roose, T. (2017). Imaging microstructure of the barley rhizosphere: particle packing and root hair influences. *New Phytologist, 221*(4), 1878-1889.

Naveed, M., Ahmed, M. A., Benard, P., Brown, L. K., George, T. S., Bengough, A. G., ... & Hallettt, P. D. (2019). Surface tension, rheology and hydrophobicity of rhizodeposits and seed mucilage influence soil water retention and hysteresis. *Plant and soil, 437*(1-2), 65-81.

Cooper, L. J., Daly, K. R., Hallettt, P. D., Koebernick, N., George, T. S., & Roose, T. (2018). The effect of root exudates on rhizosphere water dynamics. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 474*(2217), 20180149.

Naveed, M., Brown, L. K., Raffan, A. C., George, T. S., Bengough, A. G., Roose, T., ... & Hallettt, P. D. (2017). Plant exudates may stabilize or weaken soil depending on species, origin and time. *Plant and Soil, European Journal of Soil Science, 68*(6), 806-816.

Koebernick, N., Daly, K. R., Keyes, S. D., George, T. S., Brown, L. K., Raffan, A., ... & Hallettt, P. D. (2017). High-resolution synchrotron imaging shows that root hairs influence rhizosphere soil structure formation. *New Phytologist, 216*(1), 124-135.