Harnessing Interactions between Plant Roots and Soil Biology in Undisturbed Soil

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KEY MESSAGES

• Controlled traffic farming systems originally developed to reduce the compaction caused by random wheel traffic across farmed land. The impacts of excessive soil compaction on plant roots and soil organisms have been widely demonstrated and generally accepted, but we will briefly review them.

• Modern controlled traffic farming systems usually incorporate no-till or minimum disturbance principals and increasingly feature guidance systems for more precise placement of seed rows and other inputs. As a consequence we are farming increasingly undisturbed soil.

• Our scientific understanding of the interactions of plant roots and soil biology in undisturbed field soil is generally poor because most information about interactions of roots and soil organisms have been conducted in laboratory media, uniform soil in pots or in disturbed field soil.

• We will highlight some recent examples where new scientific techniques are beginning to shed light on the interactions between plant roots and soil organisms in undisturbed soil. This understanding will assist us to design farming systems which avoid negative interactions and harness positive interactions between crops and soil biology.

COMPACTION AND SOIL BIOLOGY

Compaction can affect the soil biology by direct physical damage to plant roots and larger soil fauna, or indirectly through changes in aeration, pore size distribution and soil water status which affect roots and a number of soil micro-organisms. The majority of these effects have been known for many years as summarized in Table 1.

Table 1 – Roots and soil organisms are influenced by compaction

Organism/s	Effect	Reference
Roots	reduced growth	Atwell (1990)
Pseudomonas	increased	Watt *et al.* (2003)
Springtails/mites/earthworms	decreased number	Aritajat *et al* (1977)
Bean root rot	increased	Burke *et al* (1972)
Sugarbeet nematodes	increased	Cooke & Jaggard (1974)
Phytophthora (corn)	increased	Allmaras & Dowdy (1985)
Soybean rhizobia	reduced nodules	Voorhees *et al* (1976)
Mycorrhizal fungi	reduced infection	Safi (1981)

These negative impacts of compacting loose surface soil can be readily reproduced in laboratory or pot studies and we understand much about how they can ultimately influence crop performance. Agronomic benefits have flowed from alleviating soil compaction by mechanical amelioration, and avoiding re-compaction through adoption of controlled traffic systems. Increasingly, these systems incorporate no-till so that the surface soil moves from a cycle of compaction, disturbance and re-compaction to a permanently undisturbed state, while the sub-soils are rarely disturbed.

WHAT DO ROOTS SEE IN UNDISTURBED SOIL?

Undisturbed soils generally develop a very heterogeneous structure with zones of high soil strength and many large cracks and pores within which roots can be constrained. Often previous roots have occupied these spaces which become niches that successive generations occupy. The soil around these "biopore" walls can be rich in micro-organisms. Direct contact between the roots of current crops and those from many previous crops can be substantial, and the dead roots can harbour many different organisms. This close association can influence nutrient transfer, disease infection, symbiotic interactions and many other unknown effects on plant growth. The picture we may get by removing a soil core and mixing it for nutrient or disease analysis will be a very different picture to what the roots are really seeing.

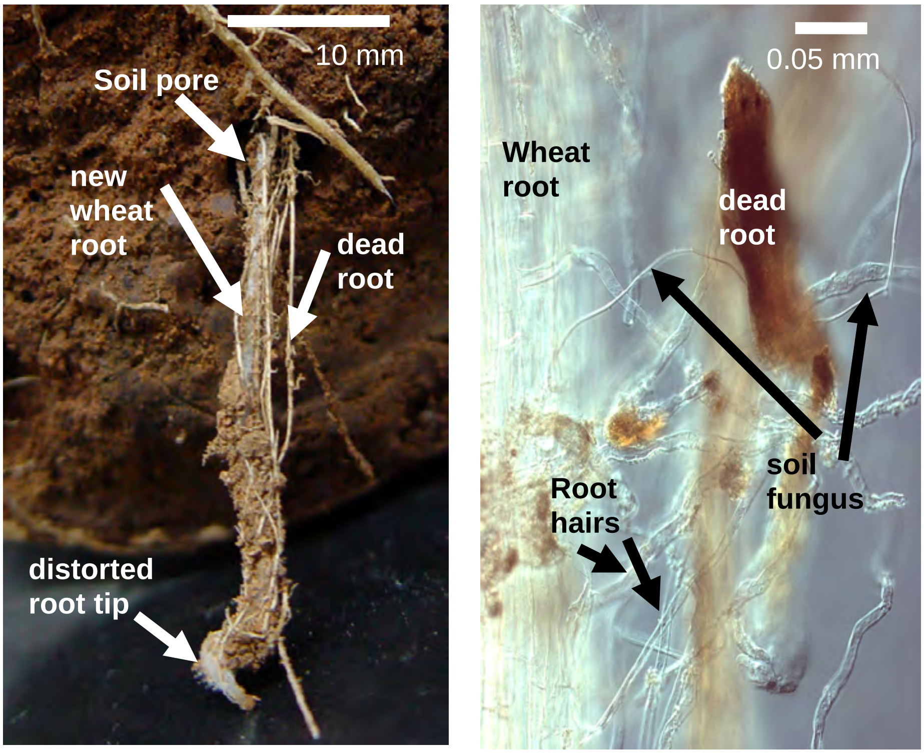

Figure 1: *Left*: Wheat root emerging from a pore in undisturbed soil, with many dead roots stuck to it. The growing tip is distorted and growing slowly from hard soil. *Right*: Microscopy view of intimate contact between crop roots, dead roots from previous crops, and soil organisms that occur frequently in undisturbed soil. (Images adapted from Watt et al., Functional Plant Biology, 2005)

THE HARDEN LONG-TERM STUDY - A CASE STUDY OF BIOLOGY IN UNDISTURBED SOIL

We have conducted a long-term study using no-till, control traffic principles at Harden in southern NSW since 1990 (16 years) and have compared many aspects of the soil biology in undisturbed, no-till system with that in a cultivated system. Despite improvements in most soil characteristics under long-term no-till as expected, the wheat crops consistently had reduced early vigour, an effect shown to be more widespread both across NSW and worldwide.

After investigating the usual suspects for reduced growth (temperature, nutrients, water, soil strength) the breakthrough came when we demonstrated that fumigation could overcome the problem – indicating the constraint was biological. Further investigations ruled out the major disease organisms but showed it was inhibitory bacteria called *Pseudomonas* specific to the root surfaces of wheat seedlings from direct-drilled sites that were reducing vigour – but how?

To understand how soil hardness and *Pseudomonas* bacteria were inhibiting growth we used new microscopy techniques to study the roots and associated soil organisms of intact field-grown roots. This revealed that most roots in no-till soil were constrained in cracks and pores made by previous roots and soil organisms, and grew much slower and distorted more than roots in cultivated soil. They accumulated the *Pseudomonas* bacteria on the slow-growing root tips (but not other bacteria), and the root tips were sensing the growth inhibiting substances and slowing shoot growth.

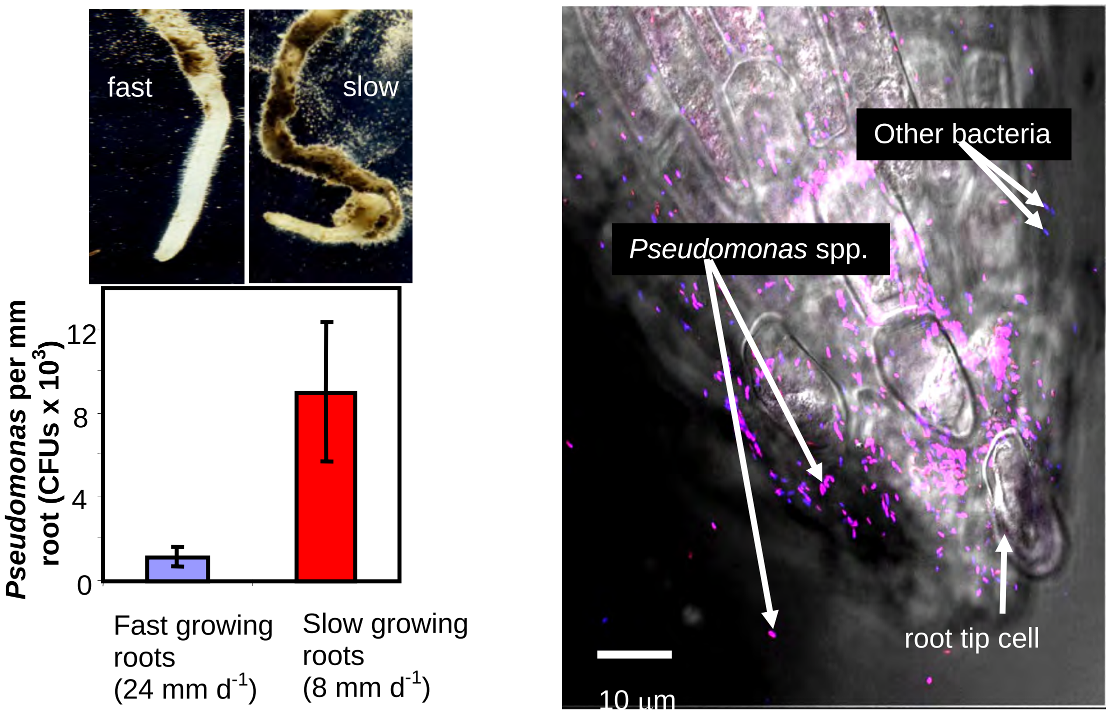

Figure 2: *Left:* Fast-growing wheat root tip from cultivated soil beside a slow-growing, distorted root from direct-drilled soil. The graph shows that slow-growing direct-drilled roots have higher numbers of Pseudomonas bacteria. *Right*: Wheat root tip with bacteria feeding off chemicals released from tip cells. Bacteria labeled with coloured probes. (Image adapted from Watt et al., Environmental Microbiology, 2006)

This exemplifies how important an understanding of soil biology in undisturbed field soil and its interaction with plant roots can be to explain crop response and develop solutions. These detailed studies finally explained how management strategies already used by growers such as early sowing into warmer soils and cultivation below the seed, reduced the negative impact of no-till. They also paved the way to investigate new cultivars of wheat and other crops with inherently fast root growth that may be better adapted to new undisturbed farming systems.

WHAT ABOUT PRECISION AND SOIL BIOLOGY?

Precision farming and controlled traffic provide an opportunity to control the placement of root systems – crop rotation in space rather than time. This has powerful implications for soil biology since the majority of potentially active soil organisms at sowing are stuck to dead roots from previous crops, and the new crop roots release carbon and signals that feed and stimulate these organisms. The net effect is a specific community of organisms very close to the new crop roots that can either inhibit (e.g. via diseases or toxins) or benefit crop growth (e.g. rhizobia and nitrogen fixation, nutrient mineralization, disease suppression, growth promotion). This contact is particularly high in undisturbed soils with high bulk density because dead and new roots are forced into the same spaces year after year (see again Images in Fiogure 1).

Reducing infection by root and crown diseases by controlling row placement in this way has been demonstrated by Matt McCallum in south Australia (see abstract in this booklet) and Steve Simpfendorfer in northern NSW (Northern GRDC Update 2005) with yield benefits from 5 to 10%. The approach was less effective under continuous cereals because enough inoculum remained in the original row position after 2 years to re-infect the crop.

Major disease pathogens may not be the only component of the soil biology which can influence plant productivity as demonstrated at Harden. Recently we started a project to investigate opportunities to improve the growth of successive wheat crops in undisturbed, no-till soil with a focus on rhizosphere bacteria. We are building on preliminary evidence that some wheat varieties perform better under these conditions, and that this is related to the different types of bacteria which accumulate around their roots. The differences are likely to be related to the different compounds released by the roots (carbon and signals that stimulate soil organisms) and the resulting profile of organisms left on root remnants. Opportunities may exist to manipulate these beneficial interactions using successions of selected varieties and/or manipulating row placement.

Controlled traffic and precision agriculture with no-till farming will benefit from better understanding about soil biology and roots in undisturbed soils. This will lead to many opportunities to manage the natural soil biology, and placement of introduced beneficial organisms such as inoculants.

FURTHER READING

Sturz, A.V., Carter, M.R. and Johnston, H.W. (1997) A review of plant disease, pathogen interactions and microbial antagonism under conservation tillage in temperate humid agriculture. *Soil and Tillage Research* **41**, 169-189.

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