Soil biology

Sustainable olive orchards

By JUSTINE COX

Soil contains an incredibly diverse and abundant suite of organisms, from microscopic bacteria to giant tunnelling earthworms (collectively called the soil biota). Generally 75% of soil organisms are found in the top 10cm of soil. This is because the requirements for these organisms include adequate moisture, oxygen and carbon (food).

The top few centimetres of topsoil are usually teeming with soil organisms, which can be grouped according to size (see Table 1).

A single gram of soil (about one-fifth of a teaspoon) can contain more than 100 million bacteria, 1 million actinomycetes and 100,000 fungi with hyphae, which, if strung together would measure five metres in length. The diversity of soil easily rivals that of any other above-ground ecosystem (see Table 2).

SOIL BIOLOGY AS A PART OF SOIL HEALTH

Soil organisms contribute to soil structure, water-holding capacity, pH and nutrient availability while the physical and chemical soil environment determines what organisms can live in the soil profile. There is a strong interaction between all these components; changes in one aspect will influence the others. The holistic approach of looking at the soil as a system will enable us to use the natural soil processes to improve orchard production, health and yield in the long term.

ORGANIC MATTER DECOMPOSITION

One major function of soil biota is the breakdown and release of nutrients from organic matter decomposition. Carbon is the major component of organic matter and a vital source of energy. The microbial population (biomass) is responsible for the rate of this breakdown – the more diverse and abundant the carbon source is, the more diverse and abundant the microorganisms are. Microorganisms make up 80-90% of the soil's biological activity. Soil physical characteristics, climate, plant tissue composition and the chemical status of soil also influence breakdown rate.

Other organic nutrients are mineralised by the microorganisms, such as nitrogen, phosphorus and sulphur into nitrates, phosphates and sulphates. These mineral nutrients can then be taken up by the plant roots, leached down the soil profile or lost through volatilisation (turned into a gas). Nitrifying bacteria (*Nitrosomonas* and *Nitrobacter*) convert ammonia nitrogen into plant-available nitrate. Phosphorus-solubilising bacteria (such as *Penicillium* spp) convert soil-bound P into phosphate. Mycorrhizal fungi form close associations with plant roots to increase the plant's ability to take up phosphorus (and zinc). The fungi receive a benefit from the plant in the form of carbon substrates for its own growth. Olives have several mycorrhizal species associated with their roots.

Table 1

Classification	Examples	Size*
Microflora	bacteria, fungi, algae, actinomycetes	1µm–20µm
Microfauna	protozoa, nematodes	4µm –200µm
Mesofauna	collembola, mites	200µm–10mm
Macrofauna	earthworms, beetles, termites	>10mm

* 1 µm = 1/1000mm

Table 2: Number of species of various soil organisms
(Hawksworth and Mound 1991; Brussaard et al., 1997; Wall and Moore, 1999).

***Size Class* Organism**	**No. species described**	**Estimated no. species**
Microorganisms		
Bacteria and archea	3200	90,000
Fungi	approx. 35,000	1,500,000
Microfauna		
Protozoa	1500	100,000
Nematodes	5000	500,000
Mesofauna		
Mites (Acari)	approx. 30,000	
Springtails (Collembola)	6500	
Diplura	659	
Symphyla	160	
Pauropoda	500	
Enchytraeids	>600	
Macrofauna		
Root herbivorous insects	approx. 40,000	3000
Millipedes (Diplopoda)	10,000	
Isopods	2500	
Termites (Isoptera)	2000	
Ants (Formicidae)	8800	
Earthworms (Oligochaeta)	3627	

Nitrogen fixing bacteria that live inside nodules of legumes convert atmospheric nitrogen to plant-available forms (*Rhizobium* and *Bradyrhizobium* spp). These are symbiotic microorganisms: the plant provides the right environment for the organism and in return gets nitrogen supplied. There are non-symbiotic microorganisms that live freely in the soil and fix atmospheric nitrogen near crop residues and the rhizosphere (*Azospirillum* and *Azotobacter*).

IMPROVEMENT OF SOIL STRUCTURE

Soil microorganisms secrete sticky polysaccharide chemicals that bind soil particles and organic matter together. These clumps are then bound into larger aggregates by the threads of the fungi. The fungi maintain strong stable aggregates, which can withstand disturbances such as water erosion and destruction by machinery. Soils with good structure provide pore spaces for a diversity of organisms and a stable habitat for all biota. Larger macrofauna such as earthworms and beetles tunnel into the soil, mixing and aerating the soil profile. Organic matter on the soil surface is then brought into closer contact with the decomposing organisms. The channels also improve water infiltration. Earthworms can have a significant effect on the soil's fertility because they also deposit highly nutritious waste products in the tunnel lining and new roots seek these sites out. See Figure 1. ➤

INTERACTION WITH PLANTS

Soil biota can have positive and negative effects on plants. If conditions are ideal in the soil for pathogenic organisms, then disease (or pests) can build up and decimate a crop. Pathogenic fungi can act to cause disease by invading the plant cells and mining the nutrients, or by excreting toxic chemicals to kill the plant (Gupta and Roget 2004). *Phytophthora*, *Pythium* and *Rhizoctonia* are fungal diseases of olives (and others) which rot or damage the root system of plants. Often the condition for severe disease pressure is wet soil for extended periods, which keep the roots moist all of the time. The *Verticillium* fungi also enters the roots and travels through the vascular system of the tree.

In healthy soils the high diversity and presence of antagonistic microorganisms provide natural suppressiveness to pathogenic organisms. High levels of fungal-feeding organisms (amoeba) have shown to suppress *Verticillium* and *Rhizoctonia*. In Spain, two *Pseudomonas* spp (bacteria) have been shown to delay the onset and reduce disease incidence of Verticillium wilt in olive plants (Mercado-Blanco et al 2004). In a healthy soil, native organisms out-compete pathogens, produce toxic chemicals specific to them or do not allow them to colonise root surfaces, and predators feed on them when they get too abundant.

All soils show some suppressive ability. High organic matter in soil and diverse food sources for the microorganisms will ward off a disease threat if conditions remain good. Soils that have been totally denuded of organisms – for example, by fumigation – have been shown to be very susceptible to increased disease expression afterwards.

HOW DOES MANAGEMENT AFFECT THEM?

Every management practice that disturbs the soil environment changes the soil biota. In some cases the change will be small and the system will recover. In more severe disturbance (for example, tillage) the balance of organisms may alter permanently. Most research has been focused on the grains industry, which has a dedicated body to address this issue (the Soil Biology Initiative). Reduced tillage has lead to increased microbial activity and maintained food web structure (as determined by nematode community structure analysis) but these effects were not large as the effect of climate, especially drought (Bell et al 2004).

Organic matter addition has shown to increase the soil biota in many agricultural systems including vineyards, pastures, cereal crops, macadamia orchards. Buckerfield and Webster (2000) found more earthworms in the soil under grape vines after composted mulch was applied. It also improved compaction, infiltration rates and water holding capacity of the soil, which resulted in higher grape yields without affecting quality. Compost addition under macadamia orchards in far north NSW increased microbial activity, carbon, water holding capacity and reduced the acidicity of the soil to levels soil organisms could tolerate (Cox et al 2004, available at < www.regional.org.au/au/asssi/supersoil2004/s12/oral/1460_coxj.htm#TopOfPage >.

Soil compaction from machinery use, soil erosion from bare soil surfaces and pesticides also severely deplete the soil biota and their function. These changes to the physical environment of the organisms' habitat reduce their ability to remain active in the soil. Management practices that reduce soil disturbance and improve soil habitat – for example, organic matter addition, green manuring, animal manures, reduced traffic, soft chemicals, inter-row planting – will benefit the orchard through healthy soil and healthy trees.

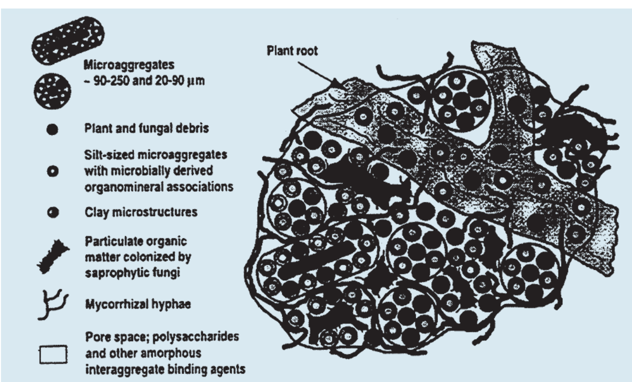

Figure 1: Conceptual diagram illustrating the diversity of organic matter and their relationships with other soil components at varying scales (from Jastrow and Miller 1998).

HOW DO YOU MEASURE THEM?

Growers cannot send soil samples off to a lab to get a soil biology test very easily. Even when there are commercially available labs that measure such things, what do they mean? Sending a soil sample for chemical analysis brings you back information about the pH, carbon content and nutrients. These numbers have usually been benchmarked for the region and an advisor will be able to tell you to add specific fertilisers or composts to prepare for the season's plant growth.

On the other hand, there is not the information available about how many organisms are required to have a functioning soil and what groups. Season, clay percentage and type, rainfall, root types, farming system and many other factors play a big part in what organisms would end up in a soil sample and so it is difficult to interpret what this means.

Soil biology researchers have used many laboratory methods to characterise the soil biota. This includes direct counts of individuals (bacteria plate counts), groups of organisms (nematodes, earthworms), biodiversity (Biolog_plates, FAME test, DNA fingerprinting), carbon-based fractions (labile C, microbial biomass C), microbial processes (enzyme activity, mineralisation rate, substrate induced respiration) and fungal/bacterial ratio (direct count, PFLA, SIR methods) (Abbott and Murphy 2004). These help us understand the dynamics of the soil biota in a particular system.

It will take time to be able to use information about the soil biota to improve orchard sustainability, although new technologies are becoming more refined to field kit stages.

One inexpensive method is the cotton strip assay (King and Pankhurst 1996). It involves inserting a piece of unbleached calico (3cm strip or 20x20cm pieces have been used) vertically into the soil for a period of time (from one week in the tropics to several months in the arid zone) and evaluating the amount of decomposition by microorganisms. The calico acts like cellulose, so this is a measure of the cellulose decomposers.

The calico can be scored visually for decomposition (1-10), measured for loss of strength or the area left after major decomposition can be estimated/measured. This method, like all others, has no benchmark, so that interpretation of "good" or "bad" is difficult at this stage. However, indications such as very low levels of decomposition in a fertile soil or region can be an early indicator of soil biology problems. Generally, the greater the amount of decomposition the better, and the pieces will show the location of greatest activity down the soil profile.

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