

## The Living Soil: Soil microorganisms and their role in soil processes

V.V.S.R. Gupta

CRC for Soil and Land Management, Glen Osmond, SA

Soil organisms (biota) carry out a wide range processes that are important for soil fertility and health in both natural and managed agricultural soils. There is a two way relationship between the soil biota and agricultural production. As soil biota play a key role in a number of key nutrient transformation processes, crop residues form the essential supply of carbon (energy source) and nutrients for microbial activity.

Soil organisms range in size from microscopic, e.g. bacteria (two thousandth of a millimeter) to centimeters (earthworms). The different soil organisms are classified into four major groups based on their body size i.e. microflora (bacteria, fungi, algae and actinomycetes), microfauna (protozoa, nematodes), mesofauna (collembola, mites) and macrofauna (earthworms, beetles, termites). In addition soil animals are also classified into various groups based on their principle food source and feeding mode, for example nematodes are classified into bacterial-feeding, fungal-feeding, plant parasitic and predatory nematodes. Soil microorganisms are also grouped, irrespective of their taxonomic classification, into groups with similar function e.g. nitrifying microorganisms, sulfur oxidizers, denitrifying microorganisms, cellulolytic bacteria and fungi. The grouping of soil biota into size classes and trophic groups helps relate their role in biological processes, as more than one individual species of soil biota are involved in any single soil biological process (e.g. decomposition of organic matter). Exceptions to this are the symbiotic relationships between rhizobia with leguminous plants and mycorrhizae-plant associations. Figure 1 illustrates the links between different groups of soil biota, in a structured flow diagram (food-web), during the processes of decomposition of crop residues. The structure of detritus food-web regulates the level of a biological process and is influenced by management practices such as tillage, crop residue management and application of pesticides.

The activity of soil organisms can be divided into four functions, i.e (i) regulation of organic matter and nutrient cycling (nitrogen, phosphorus and sulfur) including nitrogen fixation, (ii) biological degradation of agricultural chemicals (e.g. herbicides, insecticides), (iii) formation and maintenance of soil structure and (iv) interaction with plants via disease transmission, disease suppression and biocotrol of plant pathogens and insect pests. Some examples of the key microbial functions related to nutrient cycling and crop residue decomposition are given in Table 1.

The populations of microorganisms are collectively known as microbial biomass (MB) and MB acts as the engine for organic matter (OM) turnover and nutrient release. The size of MB in the surface soil may range from 250 mg per kg in a sandy soil to 1100 mg per kg in OM rich clay soil. Microbial biomass may only represent a small portion of soil organic matter (2-7%) but is dynamic and living and thus is more sensitive to management practices than total soil OM. MB is a store house of plant essential nutrients, for example

nitrogen levels in MB range from 10 mg to 50 mg per kg soil. MB also hold 5-10 mg of sulfur and 5-30 mg phosphorus per kg of soil. Nutrients held in MB are, not prone to leaching, only tied up temporarily and are released for plant uptake as a result of predation by microfauna and the death of microbes during soil drying. The distribution of microorganisms in soil is patchy, they are clumped near carbon and nutrient rich locations such as plant roots, decomposing crop residues and in micropores accessible to soluble organics. The activity of soil biota is concentrated in the top 10 cm of soil. In general 80 - 90% of soil biological activity is carried out by bacteria and fungi. Microfauna such as protozoa and free-living nematodes feed on bacteria and fungi and release nutrients tied up in microbial biomass. Bacteria help the formation of microaggregates by producing stabilizing agents such as polysaccharides and fungi through their network of hyphae are vital in physically joining soil particles to form stable aggregates. Macrofauna not only fragment organic residues there by increasing the surface area for microbial decomposition, but also help in the formation of soil aggregates and soil pores. Stable aggregates are necessary for a good soil structure.

Degradation of agricultural chemicals such as insecticides and herbicides is mostly carried out by the actions of soil microorganisms. The presence of appropriate soil microorganisms in adequate numbers is essential for the reduced persistence and leaching of contaminants from surface soil.

Plants are in contact with soil organisms through out their growth and majority of plant-microbe interactions occur in rhizosphere. A number of plant-microbe associations, such as foliar and root diseases, are also harmful for plant growth. Biological control of plant pathogens and insect pests has been successfully proven under controlled conditions and could soon become a reality.

Agricultural practices can be both beneficial and detrimental to the soil biota. The various management practices that influence populations and activity of soil biota include: (i) tillage, (2) stubble retention, (3) crop rotations, (4) application of fertilizers and pesticides, (5) irrigation and (6) soil compaction. Management effects on soil biota is either through direct effects on populations and activity or indirectly through the modification of soil environment. Since crop residues / stubble provide carbon and nutrients for soil organism growth and activity, retention of stubble is necessary to maintain a large and active soil biota. Crop residues form microsites of large and diverse populations of soil microorganisms and the quality of crop residues (e.g. C to N ratio) affects the types of soil biota it supports. Research in cereal, pasture and legume cropping systems has indicated that stubble retention increases populations and activity of microorganisms involved in crop residue decomposition, nitrification, denitrification, non-symbiotic nitrogen fixation, mycorrhizal colonization and different groups of soil fauna. However a number of plant pathogens (e.g. *Rhizoctonia solani*, *Fusarium oxysporum*, *Pythium sp.*, *Verticillium* wilt, *Alternaria* leaf spot, *Phytophthora* boll rot) survive in crop residues and residue retention increases the chances of transfer of disease inoculum from one season to the next. Research in South Australia has shown that long-term retention practices could lead to the development of disease suppressive soils. Cultivation breaks up fungal hyphae and reduces the incidence of disease. Reduced tillage practices have increasingly been adapted in Australian agriculture including in cotton-based farming

systems. Tillage not only releases the physically protected soil organic matter for microbial use but affect the biological activity through modifications to physical and chemical properties of soil. Tillage also affects the distribution of microbial populations through soil profile. Minimum tillage systems result in concentration of microorganisms near the surface (0-7.5 cm), whereas conventional tillage and stubble incorporation systems have a more even distribution throughout soil profile. Such concentration of MB in surface soil could help better utilize crop residues and reduce the persistence and leaching of agricultural chemicals. Stubble retention coupled with minimum tillage has been reported to increase the populations of soil fauna such as collembola and earthworms. Hulugalle et al. (1997) reported that even though populations of collembola were higher under minimum tilled cotton-wheat fallow (during certain periods in year) compared to that in intensely cultivated wheat, residual effects of tillage on abundance and diversity of invertebrates in vertisols is minimal.

Crop rotation effects in general are beneficial by providing disease breaks, improve plant nutrition (legume based rotations), organic matter quality and soil structure. Legumes in crop rotation add nitrogen and nitrogen-rich crop residues and thus tend to improve microbial activity and populations of a number of soil organisms. However rotations may interrupt the persistence of host-specific microorganisms (e.g. legume specific rhizobium species) and reduce the growth and persistence of beneficial microorganisms such as mycorrhizae following a canola crop.

Application of inorganic fertilizers would cause an increase in populations of microbial groups and the size of MB, unless negative changes in soil physical and chemical conditions (e.g. reduced pH) occur. Application of manures and other organic fertilizers generally increases MB and microbial activity. Application of ammonical form N and elemental sulfur fertilizers tend to cause short-term increases in populations of nitrifying and sulfur-oxidizing microorganisms, respectively. Direct effects of fertilizers on plant pathogens are not well studied but by improving plant growth and vigour, they could reduce the severity of plant disease effects.

Herbicide use is a vital component of modern agriculture, in particular under reduced till systems. With increased adoption of stubble retention and reduced till practices and the introduction of new herbicides, herbicide use will remain as an essential practice in the near future. Non-target effects of herbicides on soil biological activities may (i) result in unexpected damage to crops (e.g. increased diseased incidence) or (ii) cause undesirable effects on essential transformation processes (e.g. reduced nitrification and nitrogen mineralization). Non-target effects of herbicides could be either positive and negative. Information on the effects of herbicides and other pesticides in cotton soils is limited, especially under Australian conditions. Preliminary studies in cotton soils have indicated that application of some herbicides does affect (both positive and negative changes) the size of MB and microbial activities significantly. If herbicide application is to remain a viable practice in sustainable farming system, evaluation of herbicide effects especially from repeated and long-term use, is essential.

A large, diverse and active soil biota could help provide soil conditions for sustainable cotton production through:

- (i) crop residue decomposition and improvement of soil organic matter levels and nutrient supplying potential of soils,
- (ii) a balanced composition of different groups of biota in the detritus food web which prevents aggressive plant pathogens taking hold and improve plants ability to withstand disease effects,
- (iii) short-term immobilization of applied inorganic fertilizers there by reducing their losses through erosion and leaching,
- (iv) stable soil structure, and reduced soil erosion consequently reduced losses of nutrient rich top soil and pesticides,
- (v) reduced reliance for agrochemicals and reduced persistence of pesticides in soil and thus less off-site impacts.

Intensive cultivation and stubble burning have been an integral part of cotton growing in Australia. In addition more than one million kilograms of herbicides are applied annually in Australian cotton. Research from other farming systems suggest that retention of crop residues, reduced tillage, legumes in crop rotations, moderate use of agrochemicals are some of the management practices that could enhance biological activity and result in a balanced detritus food web which would help achieve a sustainable cotton production system. Much of the research on soil biota and their functions mentioned above is based on results from cereal, legume and pasture based farming systems from southern and eastern parts of Australia. Research regarding the soil biota in Australian cotton soils has focused on specific areas such as the ecology and management of plant diseases including biocontrol (Drs. Steve Allen and Subbu Putcha) and the ecology of mycorrhizal fungi (Dr. P. McGee). This research has provided valuable information for disease management and phosphorus nutrition of cotton. However, information on the populations and activities of a number of key functional groups of soil biota (e.g. microbes involved in stubble decomposition, non-symbiotic N<sub>2</sub>-fixing bacteria, microfauna) is lacking. In addition, the effect of management practices such as various stubble management systems, different crop rotations and repeated use pesticides on the function of key soil microorganisms requires an urgent attention.

#### **Suggested reading references:**

- Barea, J.M. (1991) Vesicular-arbuscular mycorrhizae as modifiers of soil fertility. *Advances in Soil Science*. 15: 2-40.
- Hulugalle, N.R., Lory de Bruyn, L.A. and Entwistle, P. (1997) Residual effects of tillage and crop rotation on soil properties, soil invertebrate numbers and nutrient uptake in an irrigated vertisol sown to cotton. *Applied Soil Ecology*. 7: 11-30.
- Ladd, J.N., Foster, R.C., Nannipieri, P. and Oades, J.M. (1996) Soil structure and biological activity. *Soil Biochemistry*. 9: 23-78.
- Pankhurst, C.E., Doube, B. and Gupta, V.V.S.R. (1997) Biological indicators of soil health. CAB Inc.
- Paul, E.A. and Clark, F.E. (1989). Soil microbiology and biochemistry. Academic press, New York, USA
- Roget, D. (1995) Decline in root rot (*Rhizoctonia solani* AG-8) in wheat in a tillage and rotation experiment at Avon, South Australia. *Australian Journal of Experimental Agriculture*. 35: 1009-10013.
- Roper, M.M and Gupta, V.V.S.R. (1995) Management Practices and Soil Biota. *Australian Journal of Soil Research*. 33: 321-339.
- Rovira, A.D., Elliott, L.F. and Cook, R.J. (1990) The impact of cropping systems on rhizosphere organisms affecting plant health. In "The Rhizosphere". (Ed. J.M. Lynch) pp. 389-436. John Wiley, New York, USA.

Research in cotton soils is funded by the Cotton RDC and in southern Australia funded by the LWRDC and the CRC for Soil and Land Management.

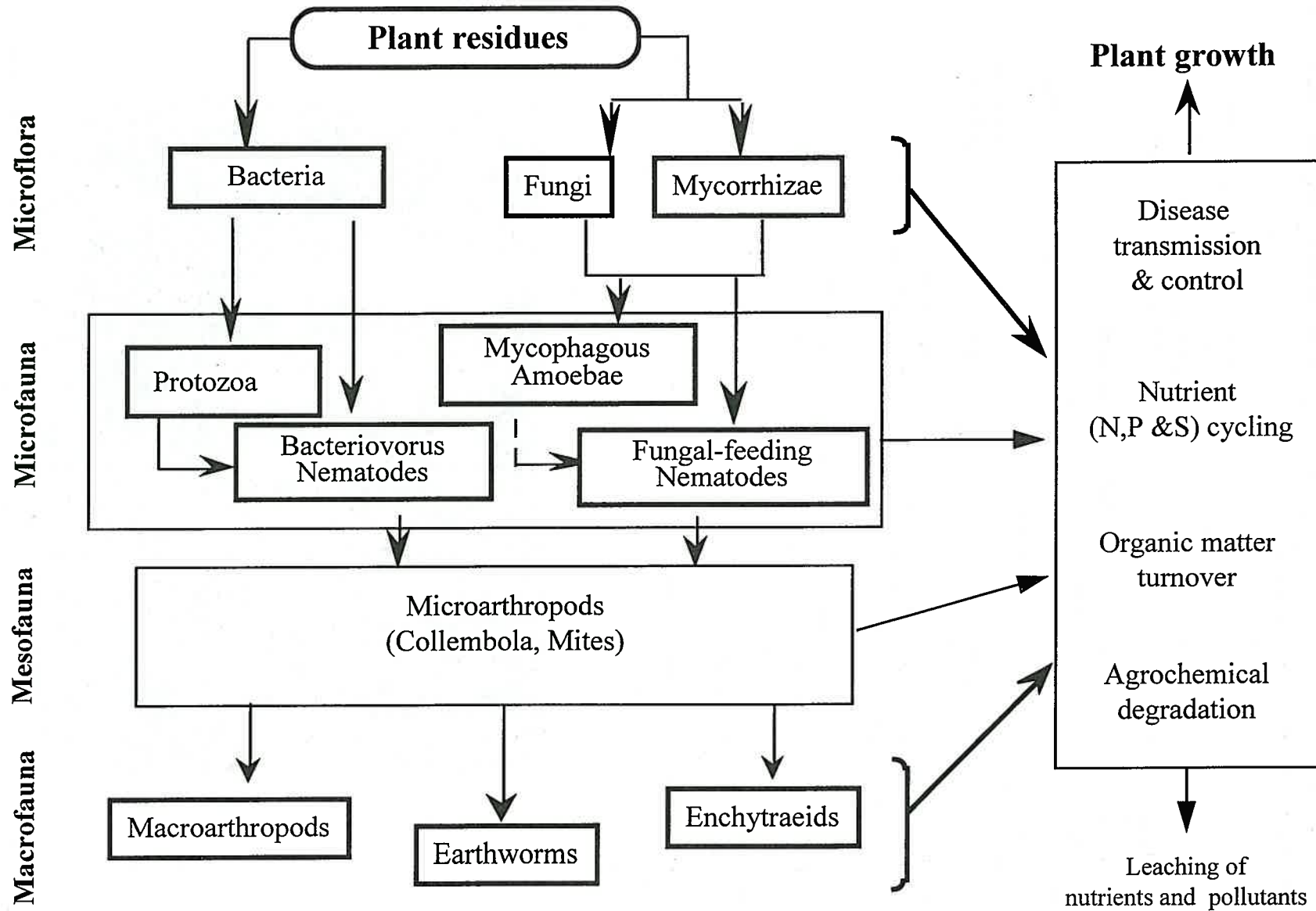


Figure 1. The different groups of soil biota are linked in a detritus food-web model in order to express their role in key soil biological processes.

**Table 1. Some examples of key microbial functions in soil**

TYPE OF MICROORGANISM	FUNCTION IN SOIL
<b>Organisms that add nutrients to soil</b>	
<i>Nitrogen fixing microorganisms</i>	
Symbiotic N <sub>2</sub> -fixing bacteria (e.g. <i>Rhizobium</i> and <i>Bradyrhizobium</i> species)	Fix atmospheric nitrogen in symbiosis with legume plants.
Non-symbiotic N <sub>2</sub> -fixing bacteria (e.g. <i>Azospirillum</i> , <i>Azotobacter</i> species)	Fix atmospheric nitrogen in bulk soil, near crop residues and in rhizosphere.
<b>Organisms that transfer nutrients into plant available forms or facilitate their uptake by plants</b>	
Nitrifying microorganisms (e.g. <i>Nitrosomonas</i> and <i>Nitrobacter</i> species)	Convert ammonia nitrogen into plant available nitrate form.
Sulfur oxidizing microorganisms (e.g. <i>Thiobacillus thiooxidans</i> ; most heterotrophic bacteria and fungi)	Convert elemental sulphur and organic sulphur into plant available sulphates.
Mycorrhizae (e.g. Vesicular Arbuscular Mycorrhizae, VAM) (except for crops such as Canola)	Facilitate the uptake of phosphorus and zinc by most agricultural crops.
<b>Organisms whose action results in the loss of nutrients from soil</b>	
Denitrifying microorganisms (e.g. <i>Thiobacillus denitrificans</i> )	Convert nitrate nitrogen into nitrogen and nitrous oxide gasses.
Sulphur reducing bacteria (e.g. <i>Desulfovibrio</i> species)	Reduce sulphate sulphur into hydrogen sulphide gas.
<b>Organisms involved in the decomposition of crop residues</b>	
Cellulolytic bacteria and fungi (e.g. <i>Cellulomonas</i> species)	Decompose cellulose and like compounds in crop residues.

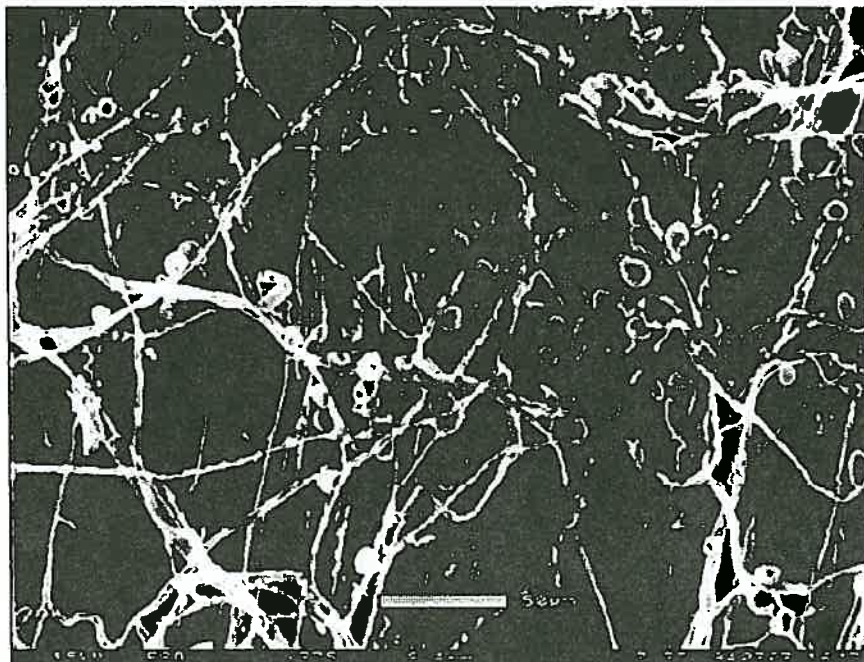


Photo. Scanning electron micrograph of crop residue colonized with fungi, bacteria and protozoa.