Life under the soil surface in pasture systems

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Abstract: Pastures with the mixed composition of plant types have the potential to support diverse below-ground biota communities. In pasture-crop rotations, tillage and other management practices can be tactically used to gain biological benefits from pasture without causing a set back to biological functions and biodiversity.

Key words: microflora, soil fauna, decomposition, mineralization, grazing

Plants are the major source of available carbon for biological activity. The quality and quantity of carbon inputs from plants (through exudation and above- and below ground plant residues) and plant-induced changes in soil physical and chemical properties have major influence on the functioning of various microbial groups in soil. Unlike annual crops, pastures are composed of mixtures of plant types (legumes, grasses, C3, C4). The availability of carbon in pasture systems is mediated strongly by grazing management through above-and below-ground plant growth in response to grazing and thus impacts on soil biological activity (Figure 1). Therefore, the development of options to manage soil biota should consider pasture composition and carbon inputs mediated through grazing management, in addition to soil organic matter.

Soil is one of our most precious non-renewable resources and the soil biota represents a large portion of the earth's biodiversity. Soil organisms regulate a majority of ecosystem processes in soil (Table 1 and Photo 1) that are essential for plant growth, soil health and sustained productivity. Soil organisms can be grouped according to their size (e.g. microflora, microfauna, mesofauna and macrofauna), phenotypic (morphological) characteristics (e.g. *Bacillus* sp. vs. *Rhizobium* sp.), function (e.g. nitrifying microorganisms) and trophic preference (e.g. bacterial or fungal feeding nematodes).

In a low input farming system, a large, diverse and active soil biota helps to provide soil conditions for sustainable pasture production through (1) improvement of nutrient supplying potential of soils and input use efficiency (e.g. N_2 fixation and N mineralization, P uptake, water use), (2) preventing aggressive plant pathogens taking hold, (3) improving plants' ability to withstand disease and (4) stabilizing soil structure thereby reducing the loss of nutrient-rich top soil. Whereas in high input farming systems, it is essential to maintain adequate activities of key microbial groups (functions) to maximize input use efficiency (e.g. fertilizer), to reduce off-site negative environmental effects (loss of nutrients, movement of dissolved organic carbon and pesticides, soil acidity) and reduce disease incidence. The efficient use of soil resources and inputs for pasture growth requires (a) synchronization of nutrient availability to plant demands, (b) lack of constraints (plant pathogens, chemical residues, hostile subsoils) to plant growth, and (c) ability of the plant to recover from grazing. Plant-biota interactions have an important role in (a) and (b) and these are in turn heavily influenced by grazing management (linked to c – the ability of a plant to recover depends on the intensity of grazing and is related to the seasonal conditions).

Major constraints for soil biological activity in Australian environments are lack of carbon and available nutrients, and relatively short periods of optimum moisture conditions, which can vary significantly with respect to season and plant growth cycles. From the concept of microbially optimum days (based on soil moisture and temperature) we could determine the overall function for specific soil biological processes under field situations and predict the potential of biological function that contribute to pasture production (e.g. nutrient mineralization; estimates of disease suppression). The various soil and environmental factors that regulate biological activity differ for different functional and trophic groups of biota. In the majority of agricultural soils in Australia, most biota are concentrated in a thin layer of surface soil (>50% in the top 5 cm) which is prone to environmental extremes (lack of moisture and high temperatures) and loss by erosion. In addition, the distribution of biological activity in soils is patchy, concentrated in "hot spots" such as decomposing crop residues, animal excreta and the rhizosphere.

The importance of these centres of influence (microsites) is great in Australian soils, which are carbon and fertility poor. In Australian soils the two microsites that contribute to the majority of biological activity (by harbouring populations and support activity) are: (a) the rhizosphere - soil surrounding roots and (b) the soil near decomposing crop and animal residues. The soil physical and environmental factors to which these two types of micro-sites are exposed are quite different, and so they tend to support or promote different groups of soil biota (in both functional and trophic groups). The two types of micro-sites also differ in the quality of the carbon substrate available to the biota, e.g. substrates in the rhizosphere are more easily metabolizable (lower C/N ratio, less lignified material) than either the litter at the surface or dead roots (wider C/N ratio, more resistant material). The other centres of activity are associated with micro- and macro-aggregates and with bio-pores (pores created by the activity of large fauna such as earthworms, ants, beetles or previous crop roots). The contribution of soil aggregates to total microbial activity in Australian pasture soils, especially in pasture-crop rotations, is lower than in other countries because of lower carbon levels and differences in soil chemical properties. The bio-pore associated biological activity may play a significant role in the overall biological fertility of pasture soils in specific situations e.g. root zone-constrained soils. The importance of bio-pores, created by macro-fauna, in soil structure development and extension of biological activity to deeper soil layers could contribute to a large extent to the overall biological functions in continuous pastures. In pastures with large populations of macro-fauna such as earthworms, their casts could form new centers of biological activity with significant contributions to the overall soil biological activity.

Soil-Plant-Biota interactions are influenced by the size relationships of the biota participants (i.e. bacteria 1-2 μm in diameter vs. soil fauna few mm to cm) as the soil habitat is composed of differently sized pores, interconnected by necks of varying sizes. Surface soils in general are heterogeneous and the soil matrix is patchy in terms of substrates, environment and protective niches for different groups of biota.

The bio-pores associated with organic matter burial by macro-fauna (e.g. dung by dung beetles and litter by earthworms) may provide a rich haven for microbial activity in the moist deeper layers unlike the dry and hot conditions that exist in surface layers. Crop residues from the cropping phase (especially under no-tillage systems), may form centres of biological activity, but because only fresh crop residues can provide easily available carbon substrates, the contribution of crop residues may be less than expected. In addition, unlike the rhizosphere, the availability of essential nutrients for microbial activity may not be adequate with crop residues. Unlike annual crops which are normally grown as monocultures, pasture systems normally consist of several plant species and are much more variable, in morphology, space and time, than crops.

In perennial pasture systems, there are usually no single major disturbance events such as tillage, and therefore carbon inputs from plant roots and litter are the major regulating factor for biological succession in these soils. In contrast, annual tillage of soil in cropping systems is a major disturbance that re-starts microbial successional cycles. In pasture-crop rotations, tillage (or non-tillage) can have a variety of impacts i.e. direct effects on soil borne pathogen inoculum and indirect effects through changes to soil, plant and microbial factors and thus influence disease outcomes during the cropping stage. The impact of tillage is different on different soilborne disease. In order to understand its impact on disease on a particular farm or paddock it is imperative that we understand the ecology of disease or disease complexes and the environmental and management factors. For example, tillage may influence the herbicide selection and the use of Sulfonyl Urea herbicides has the potential to increase rhizoctonia disease, especially in alkaline soils.

Microbial decomposition of the litter at the surface necessitates that it be incorporated into the soil through the action of macrofauna (earthworms, termites) or mechanical disturbance (tillage), which is similar to the microbial breakdown of crop stubble in reduced till cropping systems. Decomposition of pasture root material (from dead roots and root shedding following grazing) and turnover of carbon from root exudation is influenced more by its location within the soil matrix, e.g. in macropores or encapsulated within soil particles, than the material at the soil surface. Therefore physical protection and accessibility of substrate to microbiota, both factors that are heavily influenced by soil physical conditions, play an important role in the composition and activity of various microbial and faunal groups within the soil.

In permanent pastures, especially in higher rainfall areas, soil biological activities, together with soil structural and physical conditions, play an important role in ecosystem functions both within the pasture and in the wider landscape. This is in addition to soil biological processes that are important for plant growth and productivity. The transport of nutrients, carbon and pollutants (herbicides, pesticides, animal/human pathogens) through the soil at the landscape scale depends on physical and biological soil properties. On a regional level, where the landscape is dominated by permanent pastures, the soil biological component will be more significant than it is in an annual cropping system because of the lack of regular soil mechanical disturbance. The lack of synchrony in N cycling between the production and demand for mineral nitrogen resulting in excess N accumulation within the soil profile, and it's subsequent leaching from its site of production has been suggested as one of the causes of soil acidity in pasture-based farming systems in eastern Australia.

The presence of large quantities of labile organic matter from litter and decomposing root material provides optimal conditions for the production of greenhouse gases (e.g. methane, nitrous oxides) through the activities of specific soil microbial communities such as methanotrophs and denitrifying organisms, particularly in high rainfall regions. It has been observed that majority of denitrifying bacteria isolated from a permanent pasture on a brigalow clay were N_2O producers (Weier and MacRae, 1992). As nitrate N is accumulated due to the lack of adequate sinks for the available nitrogen, the presence of large quantities of labile C from litter fulfils two of the necessary criteria for denitrification with soil water content being the major regulating factor.

What controls the effectiveness of added micro-organisms to soils?

While a variety of bacteria and fungi have been found to be effective inoculants either as biocontrol agents against different crop diseases or through plant growth promotion based on controlled environment experiments, no single microbial inoculant has yet been successful under Australian broad acre agriculture systems. The maintenance of threshold levels of populations of introduced inoculants is a significant factor in their ability to perform intended function, e.g. effective disease control, plant growth promotion. For an introduced biocontrol agent to be effective, it must first survive, establish, acclimatize and grow in field soils and interact with the pathogenic organisms alone or in the presence of plant. Unlike the *Rhizobium* inoculants, which live within the protected environment of a nodule, the soil and environmental conditions are generally harsh and not optimal for introduced microbes in Australian cropping systems. The soils are generally carbon poor, there are only short-periods of warm and moist soil interspersed with extended dry and hot periods. Research on the field based ecological aspects of inoculants has been very limited. Some of the key factors important for an introduced microorganism to be effective include:

1. Availability of energy (carbon) source or a host plant
2. Suitable habitat – each functional group of microbes requires specific habitat conditions to perform its function e.g. water, oxygen and nutrient concentration etc.
3. Protection from predators, competition from general soil microbial community.

In spite of these bottlenecks successful cases where benefits from adding microbial inoculants were observed have been reported. The use of microbial inoculants or beneficial products in broad acre agriculture should not be based on "feel-good" factor but on reliable scientific evidence.

Table 1. A list of important soil biological processes and their interactions with key ecosystem functions that affect pasture growth[1] and productivity in permanent pasture and pasture crop rotations

- Carbon mineralisation: overall microbial activity, as influenced by composition and activity of various groups of soil biota which regulates disease (suppressive soils), nutrient availability, nutrient loss (leaching, denitrification), soil loss (structure and erosion) and decomposition of litter and roots.
- Nitrogen and Sulphur mineralisation: Nitrification and denitrification related to nitrogen availability and loss, S cycling, related to pasture quality (and wool quality).
- Nitrogen fixation: symbiotic and non-symbiotic N_2 Fixation Phosphorus availability and movement: P solubilization, uptake into plants, mycorrhizal fungi.
- Soil aggregate formation and soil structure: networks of fungal hyphae and pore size distribution, soil fauna activity; related to carbon content and carbon mineralisation.
- Disease and disease suppression: pathogens, microbial suppression of disease (reducing the pathogen population or decreasing disease incidence through competition or antagonism), biological controls.
- Degradation of herbicides, insecticides and fungicides.
- Plant shoot growth promotion: to aid pasture establishment and pasture renovation by resowing (relative plant density and pasture composition).
- Plant root growth promotion: root length and volume, rate of root growth during seedling establishment, pasture renovation or regeneration, compensation for diseased roots.

[1] including aboveground growth and root growth and function

Figure 1. The role of soil biological activity in the functioning of a soil - pasture system and the key interactions between soil biota and other components of a grazing system

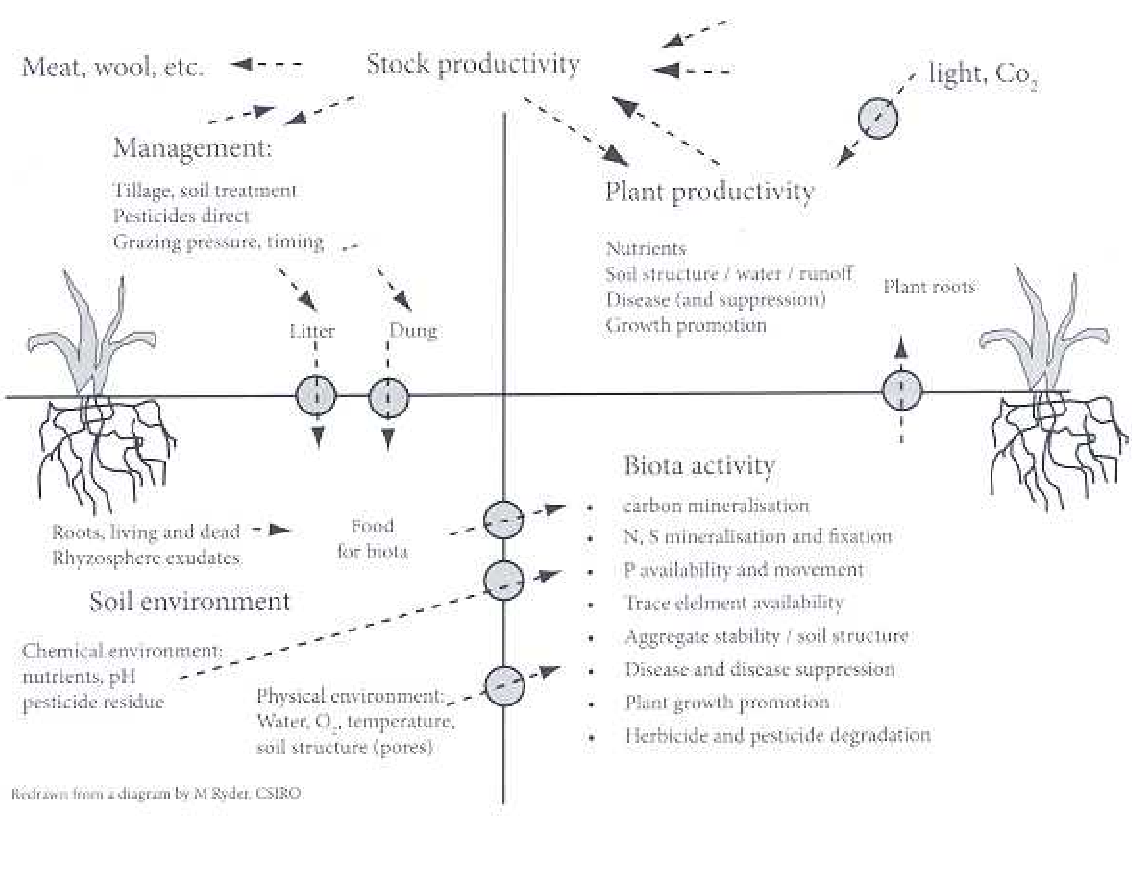
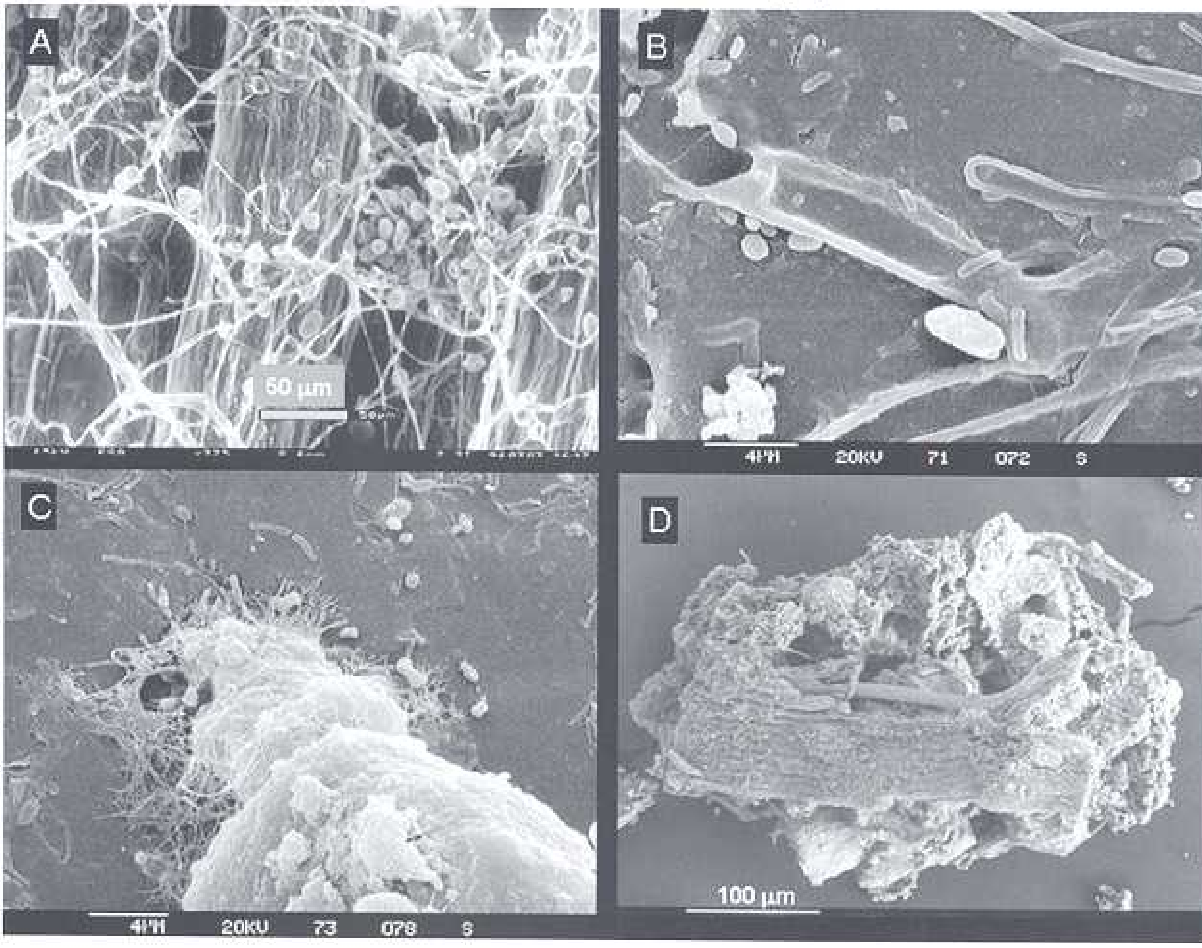


Photo 1. Scanning Electron Micrograph pictures of soil microorganisms and their functions. (A) A network of fungal hyphae, actinomycetes and protozoa near decomposing crop residues, one of the carbon-rich microsite in Australian soils, (B) Bacterial colonization and decomposition of *Rhizoctonia solani* hyphae on wheat stubble in a disease-suppressive soil, (C) A testate amoeba out of its shell feeding on bacteria, (D) Particulate organic matter and soil particles bound together by fungal hyphae, microbial glues and roots to form a stable macro-aggregate.



Reference

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