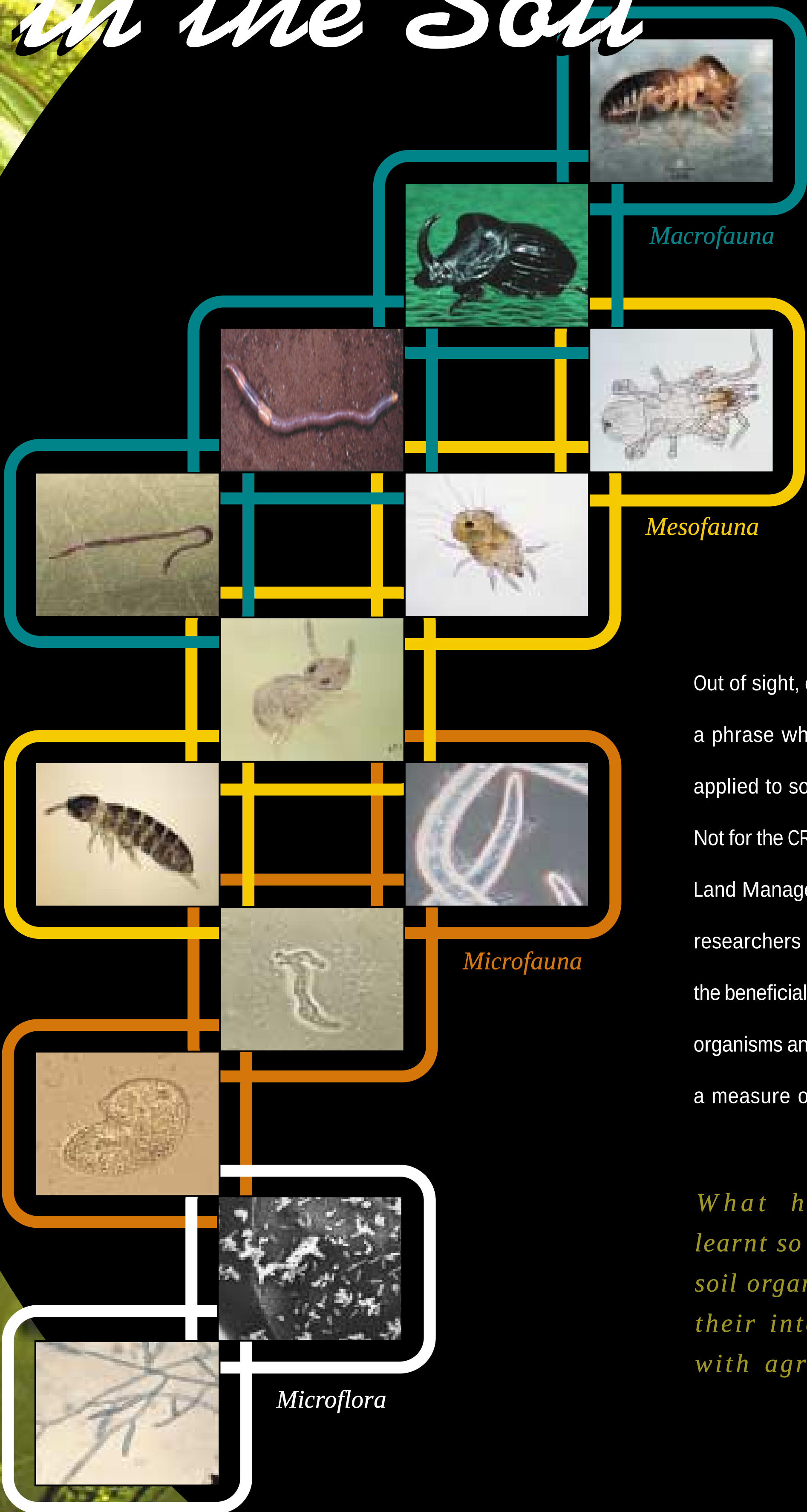
Life in the Soil

The relationship between agriculture and soil organisms



The food web - 'predator - prey' interactions help regulate the balance of species in the soil

Out of sight, out of mind is a phrase which could be applied to soil organisms. Not for the CRC for Soil and Land Management whose researchers are exploring the beneficial effects of soil organisms and their use as a measure of soil health.

What has been learnt so far about soil organisms and their interactions with agriculture?

Introduction

Soil organisms (biota) carry out a wide range of processes that are important for soil health and fertility in both natural and managed agricultural soils. The total number of organisms, the diversity of species and the activity of the soil biota will fluctuate as the soil environment changes. These changes may be caused by natural or imposed systems.

There is a two way relationship between soil biota and agricultural production.

Plant residues provide sources of energy and nutrients for the biota, which turnover organic matter (OM), improve nutrient availability and soil structure, transmit and prevent disease and degrade pollutants. Agricultural practices can be both beneficial and detrimental to the soil biota. Likewise soil biota can increase or reduce agricultural production.

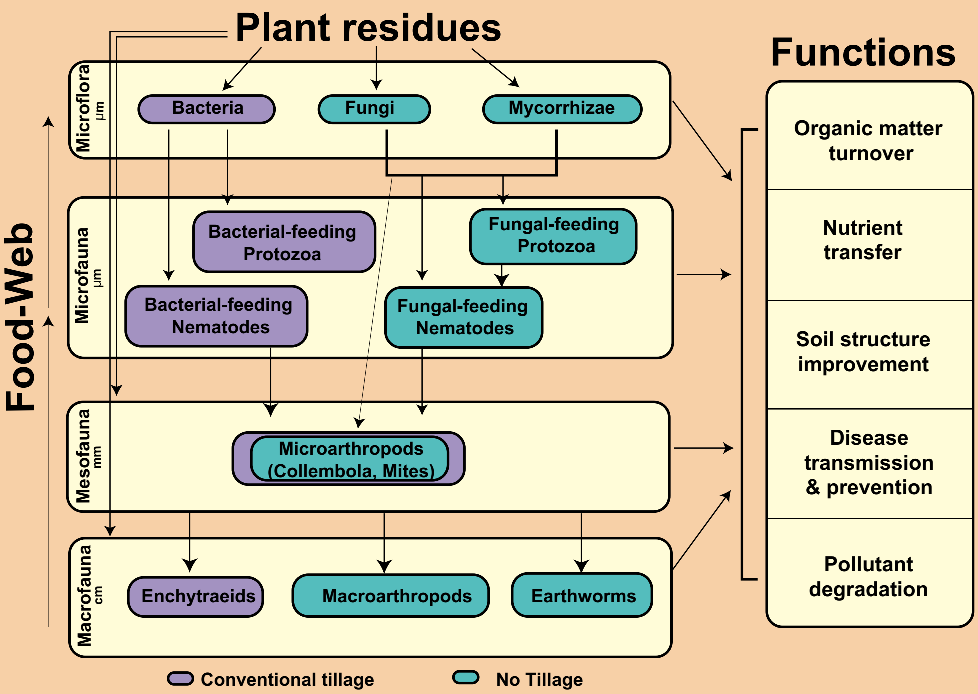
- Soil organisms range in size from microscopic e.g. bacteria to centimetres e.g. earthworms.
- The activity of soil biota is concentrated in the top 10 cm of soil.
- Millions of organisms exist but only a fraction have been identified e.g. 5% of fungi and 3% of nematodes.
- 80 - 90% of soil biological activity is carried out by bacteria and fungi.
- Resistance to extreme changes in the soil environment increases as organisms decrease in size.
- The reproductive interval reduces with a decrease in organism size e.g. bacteria reproduce themselves in hours whilst earthworms may take weeks.
- In natural and managed environments a complex food web exists. These 'predator-prey' relationships help control the balance of species present in the soil.
- When these relationships have evolved and a reduced incidence of disease occurs, such soils are termed 'suppressive'.

Microflora
Bacteria and fungi have diverse metabolic capabilities and are the principle agents for the cycling of nutrients e.g. nitrogen, phosphorus and sulphur. They may be free living or symbiotic and active in the decomposition or build-up of organic matter. They also help in the formation of stable soil aggregates.

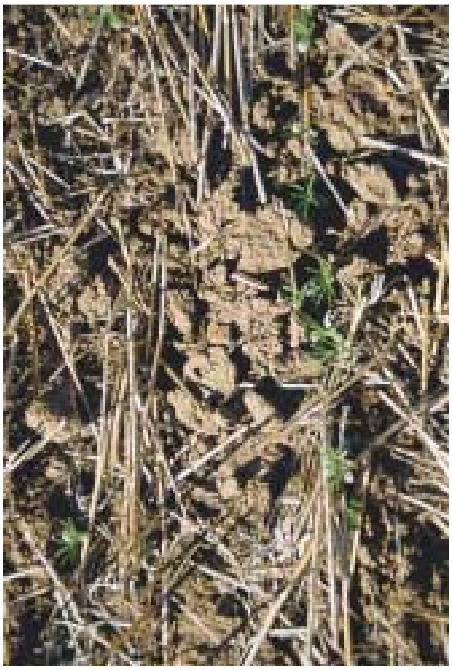
Microfauna
Protozoa and nematodes are a crucial link between microflora and larger fauna. They regulate the populations of bacteria and fungi and play a major role in the mineralisation of nutrients.

Mesofauna
Mites and collembola feed on litter and help fragment organic residues. They are predators of fungi and microfauna, playing an important role in regulating microbial populations and nutrient turn-over.

Macrofauna
Earthworms, termites and dungbeetles, etc are important biological agents fragmenting organic residues and causing a large surface area to be exposed. They also help the formation of soil aggregates and soil pores.



What do they do?



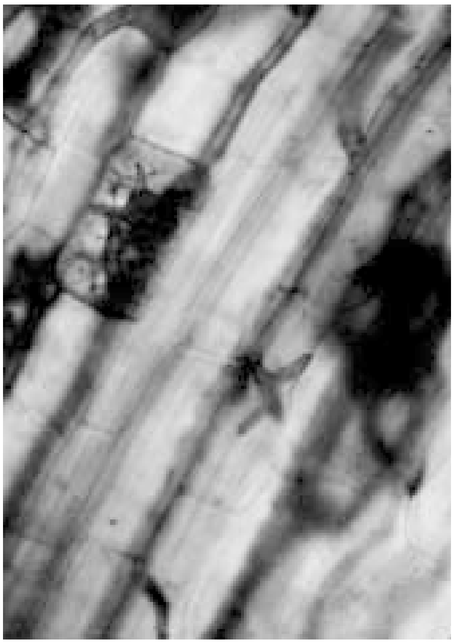
Crop residues are a major source of carbon and nutrients to soil microorganisms.

The activity of soil organisms can be divided into four functions:

1. Regulation of OM turnover & nutrient cycling,
2. Biological degradation
3. Maintenance of soil structure, and
4. Interaction with plants.

1a. Organic Matter (OM) Turnover:

- Carbon is a core element of OM and a vital energy source for soil biota.
- By decomposing OM the soil biota gain access to this carbon.
- Microbial biomass, the population of micro-organisms, acts as the engine for OM turnover and nutrient release.
- Soils with high levels of OM support a greater number and a more diverse range of biota.
- Where OM energy is plentiful, crop residue decomposition and OM accumulation will occur.
- Specific organisms breakdown different types of OM. e.g. cellulolytic micro-organisms only decompose cellulose and not lignin.
- The rate of OM breakdown relates to the soil environment, the number and type of organisms present and the chemical structure of the plant residues. Breakdown may occur in months or several thousand years.



Mycorrhizal root cross section: Mycorrhizal fungi help increase the uptake of P and other nutrients by plants.

1b. Transformation of Nutrients:

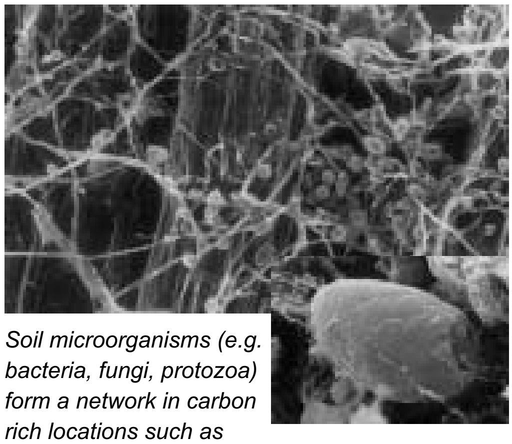
- The conversion of OM, by soil organisms, to available nutrients is called mineralisation. This process is a key element of soil fertility.
- Whilst decomposing OM to obtain carbon, other nutrients are released. These may be: soluble and leached (e.g. nitrate [NO_3]), volatile and lost to the atmosphere (e.g. nitrogen as N_2 & N_2O, sulphur as H_2S) or readily available to the plant (e.g. nitrates, phosphates and sulphates).
- In order to increase the up-take of a specific nutrient, many plants form mutual relationships (symbioses) with soil micro-organisms. Examples of symbiotic relationships include: legumes with the bacteria *Rhizobium* species to fix atmospheric nitrogen gas, and most crops with mycorrhizal fungi to absorb phosphorus and other nutrients from the soil environment.
- Mycorrhiza have been found to improve plant uptake of phosphorus. This is thought to be due to the vast 'collection structure' provided by the hyphal network of fungi.

Current research programs are looking at the opportunities that mycorrhizae offer to agriculture.

What do they do?

2. Biological Degradation:

- Soil organisms can act as bio-filters by cleaning up soil pollutants.
- Many agrochemicals are broken down by soil biota. Their effectiveness will be modified by the soil environment. Herbicide degradation is faster in soils with high microbial activity.
- Toxic elements, e.g. arsenic, chromium and mercury, can be 'locked' in the soil by microbial activity, preventing further pollution. This process is dependent on soil type.



Soil microorganisms (e.g. bacteria, fungi, protozoa) form a network in carbon rich locations such as decomposing plant residues.

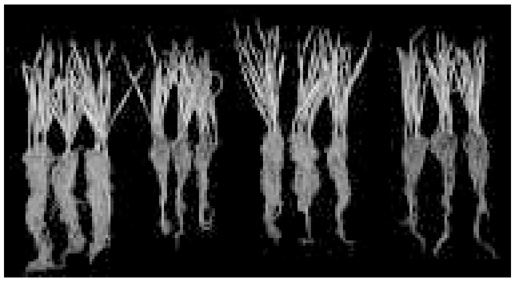
3. Improvement of Soil Structure:

- Soil structure and soil biota are interdependent.
- The mucus coverings of soil biota mix with the soil and help stick the particles together forming soil aggregates.
- Well aggregated soils provide a better living environment for soil organisms and support larger populations.
- Soil-borne fungi not only add mucus, but the vast network of thread-like hyphae hold the soil particles together improving stability.
- Movement of organisms e.g. earthworms and arthropods through the soil improves the structure by mixing and aerating the soil. This also increases water infiltration.
- Water repellance in sands is due to waxes from plant material and from products of microbial decomposition of OM. These waxes are naturally degraded by specific wax degrading bacteria, which can be introduced into soils by inoculation.

Scanning electron micrograph of fungi in a soil pore. Fungi find soil particles to form aggregates.

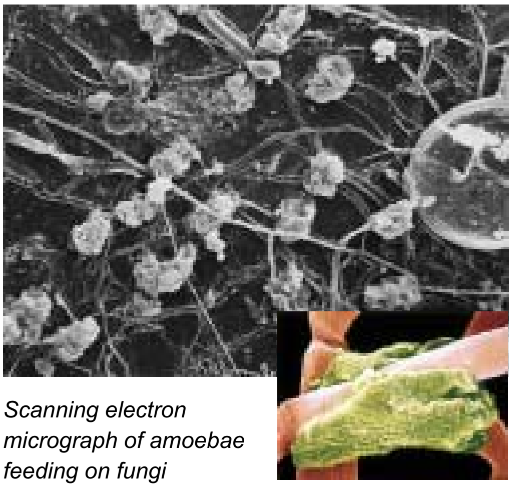
4a. Disease transmission:

- Disease causing organisms (pathogens) may affect crop growth in two ways: by invading the plant cells, or by the production of poisonous metabolites and excretory products.
- Living plants provide soil biota with a readily available source of carbon and nutrients through their leaky and dying root cells. Biota also invade the growing roots to access food.
- By invading the root, to obtain nutrients, soil organisms can disrupt the root performance or reduce root length by rotting. *Rhizoctonia* and Take-all are both fungal root diseases which have this affect.
- The degree of root damage will generally relate to the number and type of disease pathogens present.
- In laboratory experiments *Rhizoctonia*, Take-all and *Pythium* have been controlled by soil and seed inoculation with specific bacteria and fungi (bio-control agents).



Control   Ggt only   Ggt + Biocontrol bacteria

What do they do?

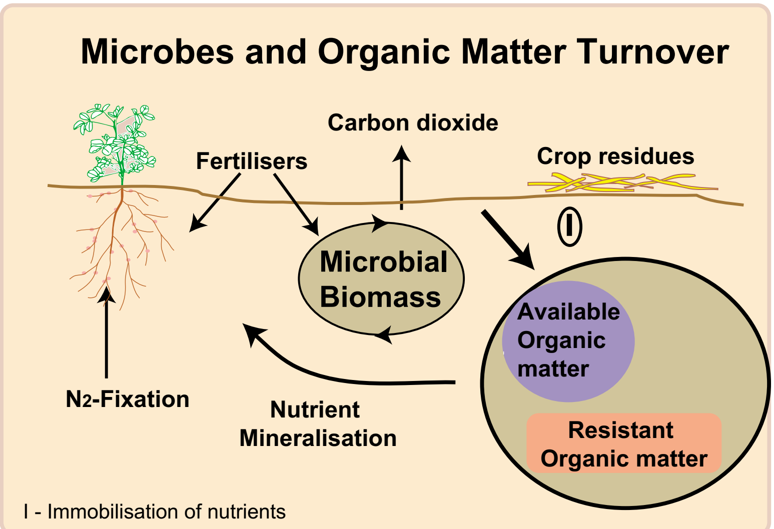


Scanning electron micrograph of amoebae feeding on fungi associated with plant residues

4b. Disease suppression and prevention:

- This is a natural condition which can be disrupted by agriculture, often resulting in pathogenic species becoming dominant.
- Soils with high levels of OM and organism activity, or a specific group of antagonistic microorganisms seem to prevent more aggressive pathogens from taking hold. These soils are termed suppressive soils.
- Soils with high levels of mycophagous (fungal-feeding) amoebae have been associated with disease suppression of *Verticillium* wilt, Take-all and *Rhizoctonia*.
- Suppressive soils are thought to be the result of 'predator-prey' relationships. There is often a lag time between the increase in population size of predator after an increase in prey population. Crop rotations may prevent the development of suppression as predators may be crop specific. For example, the incidence of Take-all will often decline in paddocks which have been planted with cereals continuously for 4 years or more.

Current research programs are looking at the distribution of, and opportunities presented by, suppressive soils to whole farm management. Other research is looking at disease control by soil and seed inoculation treatments.



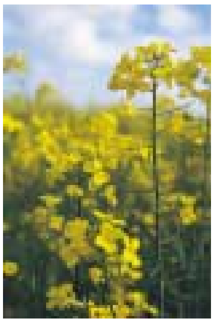
Factors Contributing to the Soil Environment

- soil texture and structure
- nutrient status
- organic matter content
- soil pH
- moisture and temperature
- surface crops and weeds
- cultivation and stubble treatments
- inputs - fertiliser, lime, agricultural chemicals, sludges, animal excreta
- compaction

A decline in the total and specific population size is considered to be detrimental to soil health, i.e. nutrient status, disease resistance, structure and stability and long term productivity.

How does agriculture

- Different soil environments will support different types and numbers of biota, e.g. soils under a canola crop will have a lower level of sulphur oxidising microbes as canola has a high demand for sulphur.
- Australia's natural soils are low in organic matter. Agricultural production often results in increased soil carbon inputs from retained crop residues and increased nutrient levels from fertilisers. As a result soil biological activity is increased.
- Different plant residues will contain varying quantities and availability of carbon (energy) and nutrients. This influences the soils biological activity.
- A challenge for agriculture is to minimise nutrient losses and to maximise internal nutrient cycling. Agricultural practices usually alter more than one soil environmental factor making it difficult to isolate which change is the most significant.



Canola

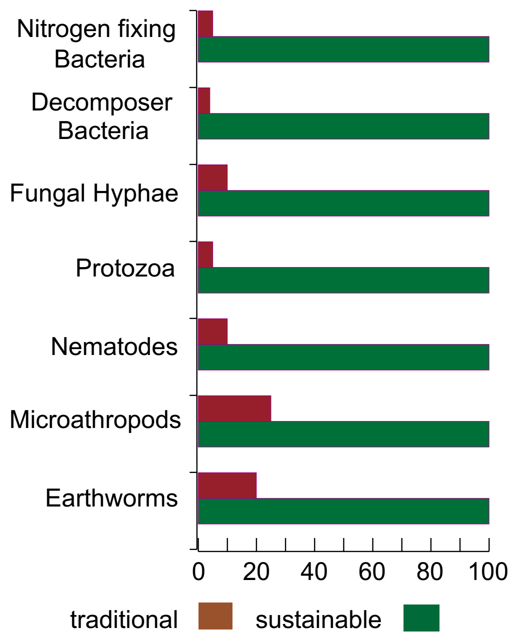
Burning removes carbon which is essential for healthy microbial activity

Scientists are working to confirm if the diversity of soil organisms is critical for sustainable agriculture.

Stubble treatment:

Micro-organisms use carbon and nutrients in OM to produce new microbial biomass. The retention of residues results in an increase in size and activity and alter the composition of the soil biota.

- Burning removes carbon and nutrient sources, limiting the activity of biota.
- Bacterial and fungal feeding protozoa numbers are reduced by stubble burning.
- Stubble retention improves the environment for soil organisms.
- Populations of bacteria which breakdown, release and fix nitrogen increase under stubble retention.
- Legume residues have a high nitrogen content. This stimulates microbial activity resulting in rapid decomposition. The increase in microbial activity under cereal residues is lower but sustained for a longer period than under legume residues. Cereal residue decomposition is slower.



The relationship between organisms in 1 kg surface soil after 10 years of different management systems. *Traditional management included burning and conventional tillage, sustainable management used stubble retention and reduced tillage.*

influence soil biota activity?

Tillage:

Cultivation alters the physical, chemical and biological components of the soil system. No-till, direct-drill systems result in significant differences in soil organism activity compared to conventional deeper tillage.

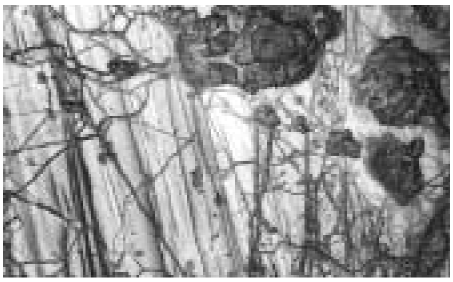
No tillage:

- OM levels are high and micro-organisms become concentrated at the soil surface.
- Residue decomposition and nutrient mineralisation is slower.
- Fungal hyphae are more prolific in the top 5cm of soil. This is beneficial in terms of desirable fungi such as mycorrhizae but negative in relation to pathogenic fungi such as *Rhizoctonia*.
- Fungal feeding nematodes, protozoa and macro fauna increase.
- 10 - 100 times more fungal feeding protozoa were counted under no-till and stubble retention treatments. These may provide controls for pathogenic fungi.
- Narrow points on cultivators used at seeding result in soil disturbance below the seed. This in combination with a three week chemical fallow, prior to seeding, reduces the severity of the pathogenic fungus *Rhizoctonia* .
- Deep burrowing earthworms in direct drilled plots improve soil structure assisting root growth and increasing the yield of annual crops.

Conventional Tillage:

- This favours organisms with short generation times, rapid dispersal and high metabolic rates. Bacteria and bactivorous fauna are dominant in cultivated soils.
- Fungal hyphae are broken by cultivation and therefore reduced.
- Organisms are distributed more deeply into the ploughed layer .
- Residue decomposition and nutrient mineralisation is more rapid due to better soil-stubble contact.
- The rapid activity results in a higher level of breakdown and a lower level of OM accumulation.
- Earthworm populations significantly decrease.
- Increased cultivation has been shown to reduce the number of root lesion nematodes, but no effect on cereal yield has been recorded.

Surface stubble



Incorporated stubble

Stubble incorporation favours bacteria and bactivorous fauna whereas stubble left on soil surface supports more fungi and fungivorous fauna.

How does agriculture

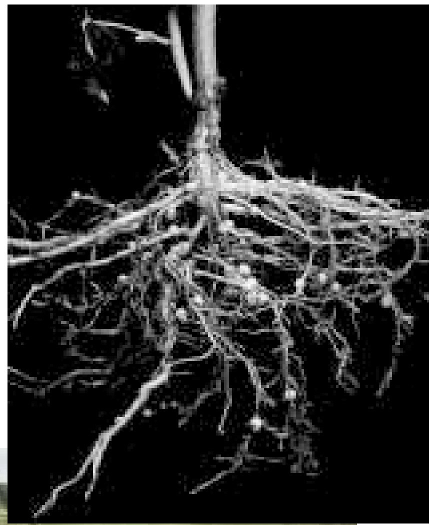
Crop rotation:

Unlike monocultures, rotations offer a number of advantages to plant production and to the maintenance of soil quality. These include disease breaks, improvements to plant nutrition, improved levels of organic matter, diverse nutrient sources for the soil biota and benefits for soil structure.

- Breakcrops can reduce numbers of host specific organisms. This helps reduce numbers of pathogenic organisms, e.g. Take-all and cereal cyst nematode (CCN), but beneficial plant specific organism numbers will decline. This may prevent the development of suppressive characteristics.
- Crops with fibrous roots e.g. cereals, are thought to provide more sites for micro-organisms to colonise compared to those with a single tap root and relatively few lateral branches, such as lucerne and canola.
- Rotations including legumes or pasture have a larger and more diverse pool of organisms. The total microbial biomass under a wheat-pasture rotation was 15% higher than under a wheat-wheat rotation.
- Compared to soil under a continous wheat rotation, soil under a pasture-wheat rotation contained a higher number of mycophagous amoebae which are suppressive to Take-all and *Rhizoctonia*.
- Cereal residues support more fungi whilst legume residues support more bacteria.
- Populations of collembola and mites were found to be higher in soils under long term pasture (70,000/ m^2) compared to soils under wheat-wheat (20,000/ m^2) or wheat-lupin rotations.
- More than 90% of collembola are located in the top 5cm of soil regardless of cropping system. Therefore numbers are prone to rapid decline if soil erosion occurs. This compares to only 55% of mites found in the top 5cm.
- Crops such as canola and mustard cause a reduction in mycorrhizae in the following crop.
- Brassica crops have been found to be better Take-all breakcrops than legumes. Decomposing brassica roots release isothiocyanates. These compounds act as a fungicide and a process of biofumigation is thought to occur.

The opportunities to exploit the biofumigation properties of brassicas are being investigated.

Rhizobial bacteria form nodules on legumes which fix atmospheric nitrogen.



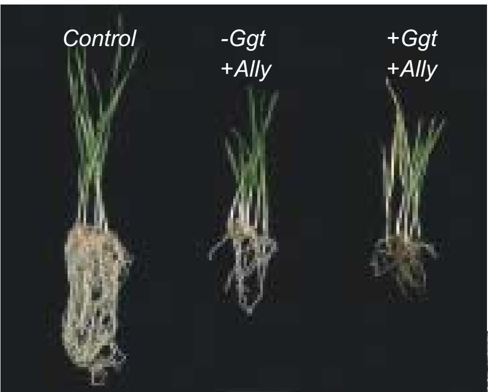
Well nodulated grain and pasture legumes in a rotation help in the nitrogen nutrition of following cereal crops.

influence soil biota activity?

Inputs:

Fertilisers

- Increased crop growth and residue inputs resulting from fertiliser applications provide energy and nutrient sources which support higher microbial populations. These beneficial effects would not be seen if fertiliser applications caused adverse effects on physical and chemical properties of the soil.
- In trials where 80kg/ha of N fertiliser was applied the microbial population fell by 25%. This was thought to be due to a change in soil pH from pH 5.4 to pH 4.5.
- Crops which have an adequate and balanced nutrient supply are less susceptible to damage by plant pathogens, e.g. applications of Zn reduce the level of *Rhizoctonia* damage in medics and cereals when Zn is limiting to plant growth.
- High levels of fertiliser can reduce the symbiotic effectiveness of soil organisms. For example, high P inputs reduce beneficial effects of mycorrhizae and high N inputs reduce N_2 fixation by microorganisms e.g. *Rhizobium.*
- Applications of liquid nitrogen fertiliser have short term negative effects on microbial activity. The system takes a minimum of 5-6 weeks to recover from a single application. This may leave a crop vulnerable from an imbalance in ‘predator-prey’ organisms.



Agrochemicals

- Foliar applied chemicals are less harmful to soil organisms than those applied into the soil.
- Herbicides may be directly toxic to soil organisms or influence the ‘predator-prey’ proportions.
- The effect on non-target organisms will depend on the rate of herbicide decomposition and leaching away from the site of the organisms. Herbicides sprayed onto stubble as opposed to bare soil, have been shown to persist longer.
- Continued use of some herbicides over several years, e.g. paraquat, have been shown to significantly depress some groups of micro organisms. Single application effects are usually short-term with microbial activity levels recovering about 40 days after herbicide application.
- Nitrifying bacteria are the most sensitive to herbicide applications.
- Increased levels of *Rhizoctonia*, Take-all and CCN have been observed in current and following season crops when sulfonylurea herbicides have been applied.
- Activity of specific organisms may increase after a chemical application due to breakdown of the food chain. For example, fungal growth increased after the application of the insecticide endosulfan due to its inhibiting effect on fungal feeding microathropods.

Patches caused by Rhizoctonia *damage on cereals may be associated with sulfonyl urea herbicide use.*

Looking at life in your soil

1. Are the *Rhizobia* in your legume crop fixing nitrogen?

Different leguminous crops require specific *Rhizobium* species for the formation of effective nodules and nitrogen fixation. If the correct Rhizobium are absent they can be inoculated into the soil.

Aim: To test your soil for the presence of Rhizobium and to assess their ability to nodulate a legume.

What you will need

1.5 kg of soil taken from the top 0-10 cm. This should be collected from several sites across the paddock.
15 legume seeds (e.g. peas, beans, lupins)
10% bleach solution - 10 ml of household bleach diluted with 100ml of water
3 large yoghurt pots - with several drainage holes in the base.
A garden soil sieve
An old tea strainer

What to do.

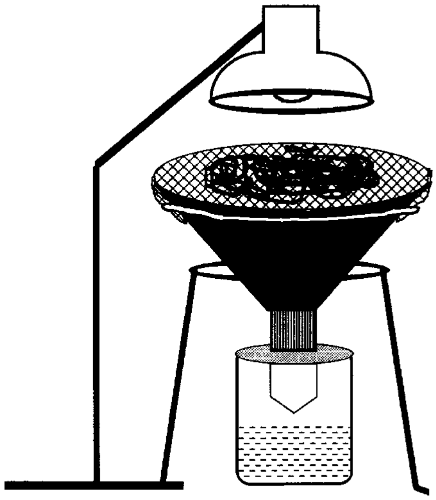
- Sieve the soil to remove any large stones and pieces of organic debris.
- Add sufficient water and mix to bring the soil to field capacity. The soil should feel wet when squeezed in the palm of the hand.
- Fill each pot with about 500 gm of the moist soil.
- Place the seeds in the tea strainer and dip them in the 5% bleach solution, covering them for a maximum of 30 seconds. Rinse with copious amounts of clean, cold water. The objective of this is to sterilise the seed surface to remove any *Rhizobium* carried by the seed. Care should be taken when handling bleach.
- Plant 3 - 5 seeds, 2 cm below surface in each pot, then place in a warm sunny position. The pots should be watered regularly to prevent the soil drying out.
- After a week thin the seedlings to 3 per pot. The plants should be left to grow for a further 4 weeks.
- After 5 weeks from sowing, carefully remove the plants from the soil. Remember it is the roots that we need so care should be taken when freeing the roots from the soil.
- Gently wash the soil from the roots and lay the plant on a sheet of white paper.
- Compare the root to the photograph of a noduled root on page 8.
- Count the number of nodules on the root. Each plant requires more than 10 nodules to achieve a high level of nitrogen fixation.
- Separate 10 nodules and cut them in half using a clean razor blade or sharp knife. Nodules which are effectively fixing nitrogen will be pink inside; those which are not will be white or green. The more intense the pink colour, the better the nodules effectiveness in fixing nitrogen.

Under the microscope:
If you have access to a microscope gently squash a nodule on to a slide. *Rhizobium* cells can be seen as ‘Y’ and ‘T’ shaped bacteriod cells.

2. Estimating numbers of mesofauna that are important for decomposition and nutrient mineralisation.

Collembolla and mites are two commonly found mesofauna. They play an important role in organic matter decomposition, nutrient cycling and regulating microbial populations by predation. An assessment of their population size is one indication of soil health.

Aim: To collect and count the number of collembola and mites in surface soil (as an indication of soil health).



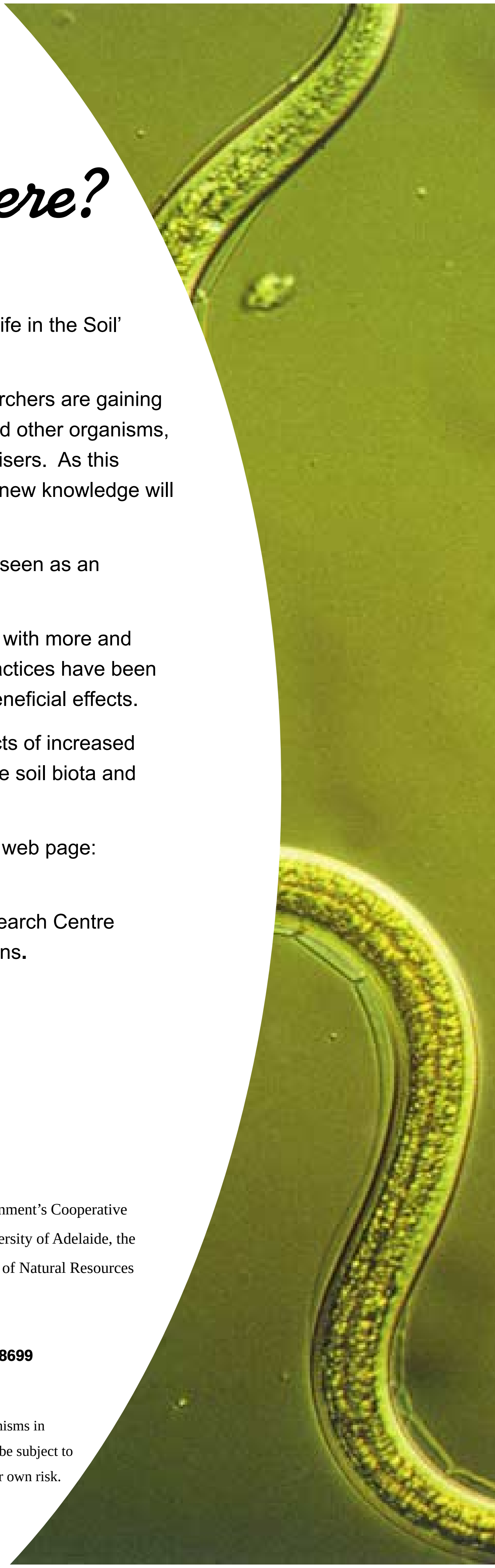
What you will need

20 g of moist crop residue and top soil. Wheat stubble or leaf litter are ideal.
70% ethanol (70 ml methylated spirits added to 30ml of clean water).
100 ml beaker or glass jar
Funnel
A piece of gauze/ fine net with 1-2 mm holes and a rubber band
An angle lamp
1 dark coloured dinner plate or similar shallow container
A powerful magnifying glass (10x or greater)

What to do.

- Place the ethanol in the beaker to about 1 cm depth.
- Place the funnel over the beaker with the spout above the surface of the ethanol (see diagram 1). You may need to support the funnel either with a clamp or a tripod stand. Seal the opening of the beaker around the funnel with plastic wrap.
- Place the gauze over the top of the funnel,and secure with the rubber band.
- Place the stubble and soil on the gauze. This may sag to form a small basket. The contents should sit away from the sides of the funnel. This prevents the mesofauna crawling back up the walls.
- Position the angle lamp over the funnel about 10cm above the surface and turn on. The mesofauna will move away from the warm and dry environment created under the lamp.
- After 24 hours switch the light off and remove the funnel
- Carefully empty the contents of the beaker on to the dinner plate and count your catch using the magnifying glass. See front page for pictures of collembola and mites.
- A soil with good levels of mesofauna activity will contain about 10-15 collembola and mites per 20g of soil and litter. Populations are generally higher at the beginning of the crop season.
- For a proper assessment of a field, several litter and soil samples should be taken across the paddock, and each analysed as above.

Where do we go from here?



Due to our inability to see many soil organisms with the human eye, the 'Life in the Soil' has not featured prominently in land management considerations.

The beneficial roles of soil organisms are slowly being unravelled. Researchers are gaining a better understanding of soil organisms, their relationships with plants and other organisms, and the impact of tillage, rotations and inputs such as herbicides and fertilisers. As this understanding develops, better management practices which include this new knowledge will be implemented.

Harnessing the benefits provided by balanced soil organism food webs is seen as an important next frontier for sustainable agricultural production.

Significant changes in farming practices are already occurring in Australia with more and more farmers retaining stubbles and moving to reduced tillage. These practices have been accompanied by increased use of herbicides which may counteract the beneficial effects.

Research in Australia is focusing on gaining a better insight into the impacts of increased herbicide use, methods to harness the natural suppressive activity of some soil biota and biofumigation properties of plants such as brassicas.

More information on Soil Biota can be found on the University of Adelaide web page: www.waite.adelaide.edu.au/school.

This information is based on research carried out by the Cooperative Research Centre for Soil & Land Management and other national and international institutions.

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