LIVING SOIL BETTER SOIL

A Better Soils Roadshow

Better Soils
An Agricultural Bureau Project

WHY IS LIFE IN THE SOIL IMPORTANT?

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Biota sustain plant growth

Soil is alive with billions of microbes, microscopic animals and larger animals such as termites and earthworms. Without this teeming population the soil is dead and unable to sustain plant growth.

Changing the balance

Before the land was cleared soil biota lived in harmony with the stable vegetative cover. As soon as the trees and scrub were cleared, the land ploughed and pastures or crops planted a new biological balance had to develop.

Two way relationship with farming

If the farming was exploitative with burning, ploughing, no liming and low fertilizer inputs, then the soil microbes and animals suffer and their numbers decline (see graph 1). When this happens, the soil processes which are essential for agriculture such as organic matter breakdown, nitrogen fixation, nitrogen cycling and soil structure maintenance all decline. This is why we have to do everything possible to maintain an active living soil population.

Remember

- An active soil biota is essential to improve and sustain agricultural production.
- We can insure a healthy soil by increasing the food supply for the microbes and soil animals.
- A healthy food supply can be achieved through increasing residue return, increasing pasture production and maintaining soil pH above 5.5.

3

Three major factors affect life in the soil:

1. **Input of Plant Residues.** Organic matter is the fuel which drives the soil biota. The higher the input of plant residues the higher the biological activity and the greater the improvement in soil fertility.
2. **Soil pH.** Soil acidity develops after land is cleared and pastures or crops grown.

   This acidity comes from processes such as:

   - nitrogen fixation by legumes
   - growing of shallow rooted crop and pasture plants
   - leaching of mineral nitrogen such as nitrate.

   Soil acidity is not directly caused by the use of superphosphate but rather by the increased plant production following the use of fertilizers.

As soils become more acidic microbial activity slows down and earthworms disappear. This results in organic matter breakdown, nitrogen fixation and productivity being reduced.

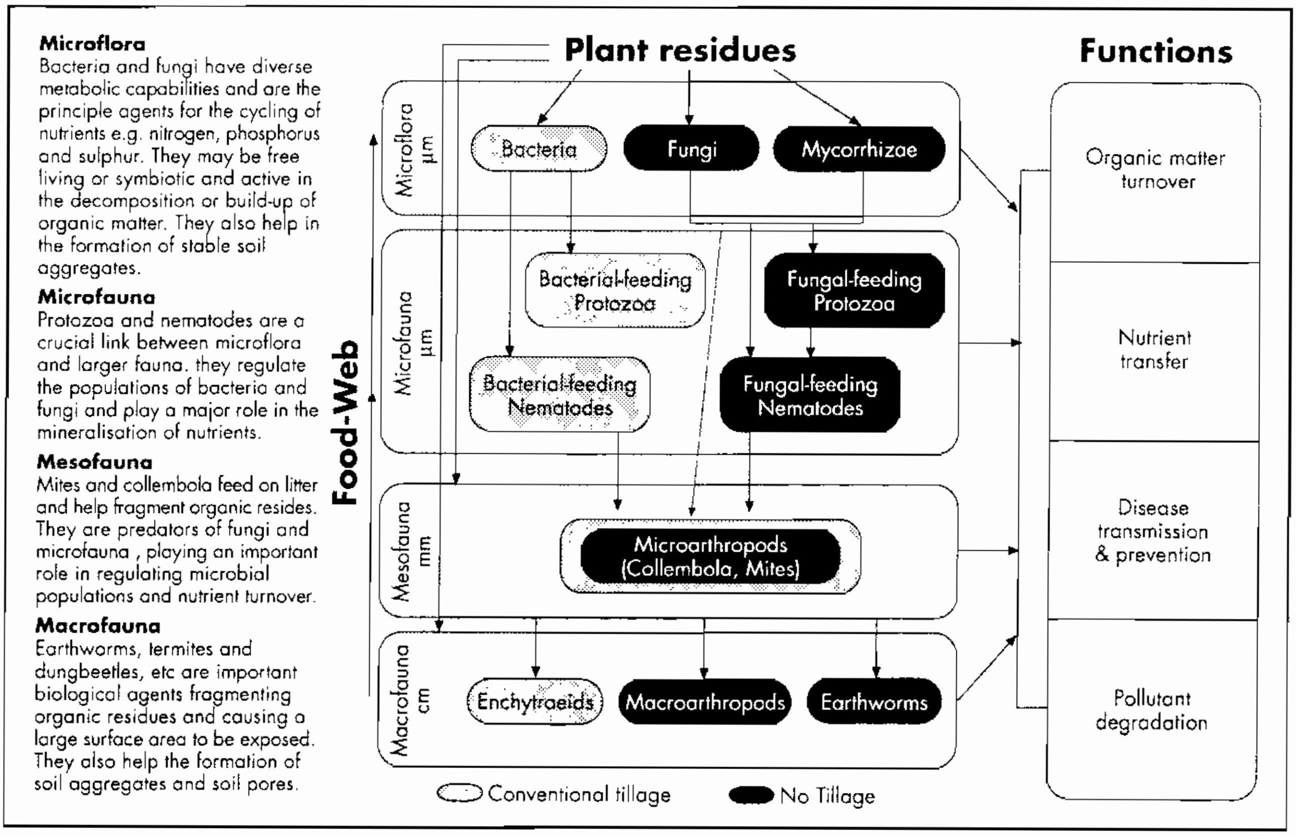
Research I did some years ago showed that microbial numbers and soil respiration more than doubled when a pasture soil was limed from pH 4.5 to 6.5. Liming of agricultural soils is a common practice overseas but here in Australia liming has not been widely adopted, much to the detriment of farm productivity.

3. **Cultivation.** Every time a soil is cultivated there is a flush in microbial activity with a loss of valuable organic matter and this leads to a breakdown in soil structure. So wherever possible, we need to minimize cultivation.

Where do soil biota live?

The majority of soil organisims are found in the top 10cm of soil. Agricultural practices which change the environment in the top 10cm of soil will impact on the type and number of soil organisims present. Many soil organisims are smaller than soil particles. If top soil is being lost by erosion so are soil organisims.

Figure 1: Soil biota carry out 5 key functions which interact with production.



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 resides. They are predators of fungi and microfauna , playing an important role in regulating microbial populations and nutrient turnover.

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.

Different production systems alter the food-web for plant residues breakdown.

Source: V.V.S.R. Gupta - CRC For Soil & Land Management

VAM - THE BENEFICIAL FUNGI THAT FEED PLANTS

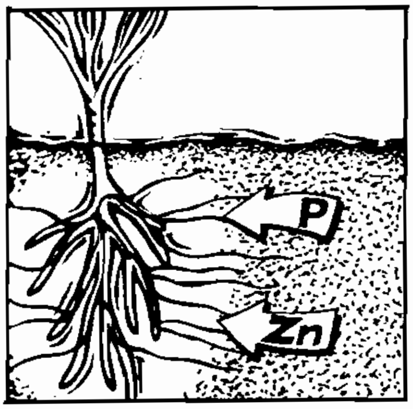
[illegible] University of Adelaide

Most plants don't just have roots, they have VAMs - vesicular arbuscular mycorrhiza. VAMs are fungi which live in a harmonious relationship with plant roots. This is a symbiosis in which the fungi provide the plant with extra nutrients from the soil, especially phosphorus and zinc, in exchange for sugars provided by the plants.

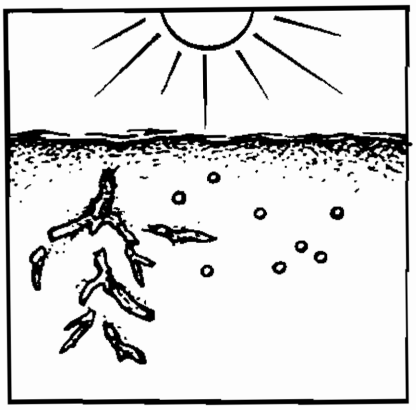
About 80% of all plants, including most field crops and many trees, harbour the fungi as an integral and normal component of their root systems.

As with all fungi VAMs also help hold soil particles together.

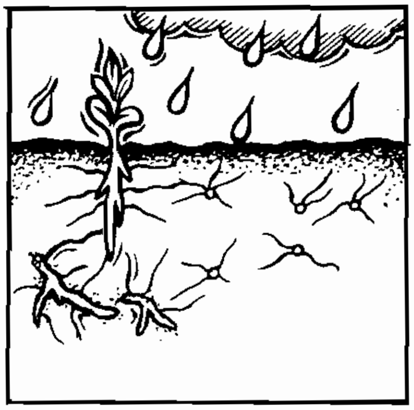
How VAMS live



VAM fungi grow inside plant roots. Hyphae absorbs nutrients beyond the reach of roots.



Summer: plants absent. Fungi survives in dead root fragments or as large spores. Fungi are dormant when soil is dry.



After rain VAM germinate from dead root fragments and spores - colonising new roots.

There are about 150 species of the fungi, which may have small preferences for different soil types and environments, but in general they are all capable of colonising roots of all susceptible plants (see Table 1 for susceptible/host crops), which is an important factor in their management.

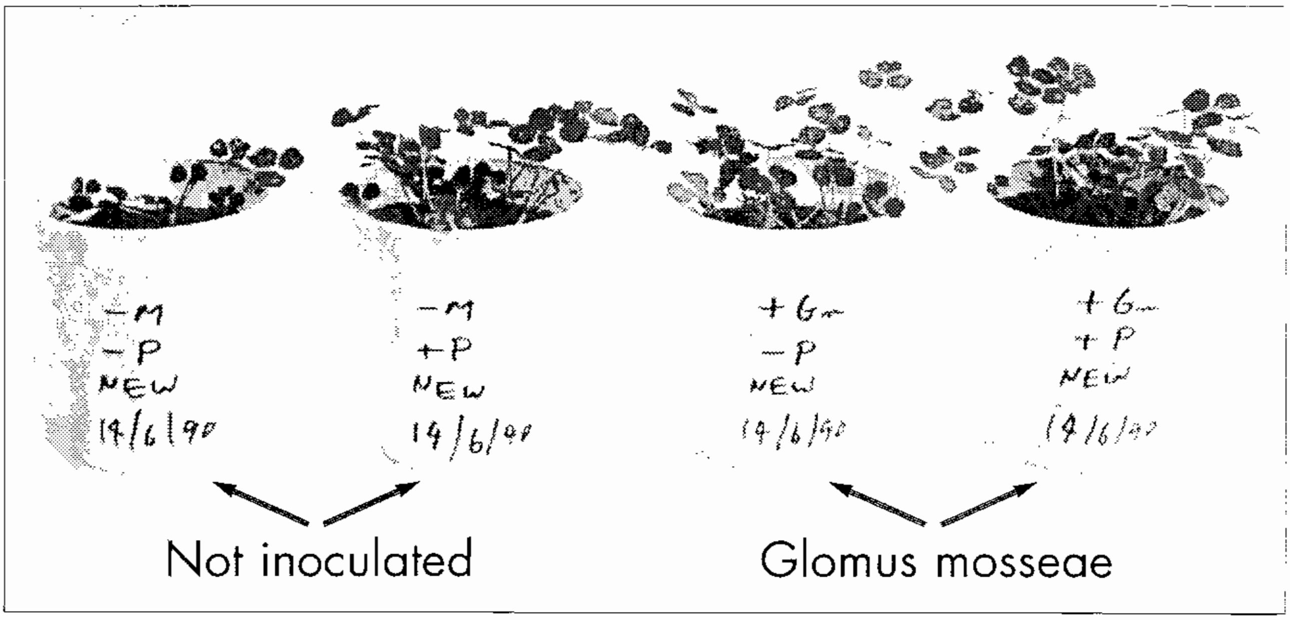
Some plants, especially trees like Eucalypts, orchids and some heathland shrubs, have a different type of symbiotic fungus which works in a similar way to VAM. If you are interested in revegetation you also need to consider the range of different beneficial fungi that may be important.

Can I see VAM in soil or roots?

VAMs cannot be seen unless the root is stained and viewed under a microscope. The VAM fungi do not cause any disease, so there is no discolouration or root distortion. This makes it difficult to determine whether they are present in the roots or the soil. However, the chances are they will be there and working to improve the nutrient uptake of your crops and the stability of your soil.

Lack of VAMs will reduce plant growth but this again may be hard to determine in a paddock situation.

Figure 2: Mycorrhizal (VAMs) and phosphate responses in low phosphorus soil



This picture shows how both phosphate fertiliser and VAMs can increase the growth of subclover. In low P soils the plants grow very badly, but growth can be increased either by fertiliser application which directly increases P supply or by VAMs which help the plant extract P even in the very deficient soil. If the balance is right then application of fertiliser and help from VAMs can work together.

How does the fungus - plant relationship work?

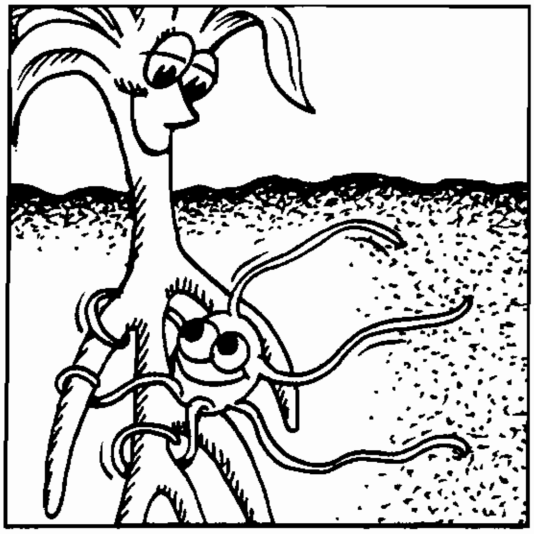
VAMs extend the plant root system and the whole mycorrhiza (fungus plus plant) can exploit the soil nutrients much more effectively than the plant alone.

Some plant nutrients, such as phosphorus (P) and zinc (Zn), move very slowly in the soil solution. Therefore, when a plant removes these nutrients from the soil near the root there can be a delay before they are replaced at the root surface. A zone of nutrient depletion may occur near the root slowing down plant nutrient uptake.

The fungi grow out into the soil, sometimes several centimetres from the root and pick up nutrients at a distance where they are still readily available. The fungal strands (hyphae) then transport the nutrients quickly back to the plant – a kind of rapid transit system - overcoming the slow movement in the soil. Tolerance to drought can be increased as the rapid transit system overcomes slow movement of nutrients in dry soil. There is no good evidence that the fungi actually transport water.

Additionally, the hyphae are very, very narrow (only about 10 millionths of a metre across, or less). This means that they have a huge surface area for nutrient absorption and they can squeeze into soil pores that are not accessible to roots which will be 10 times, or more, the width of a VAM fungal hypha.

VAM hyphae growing out of the roots bind soil particles together, like a 'sticky string bag'. This improves soil stability and can help to prevent erosion.



VAM grow inside the roots. They extend beyond the zone of nutrient depletion. They provide a rapid transit system for poorly soluble nutrients eg. P & Zn.

The benefits don't come absolutely free because the fungus needs sugars provided by the plant. Under most conditions the plant produces sugars to spare, so the 'cost' of supporting the fungi is well invested. This results in enhanced nutrient uptake and more effective use of fertilisers.

Do all plants host VAM fungi?

About 80% of plant species, including many important crops, do form VAM. Table 1 lists common crops and whether they are host or non-hosts.

Some important non-hosts which never form VAM are canola and other members of the cabbage family, lupins and beets (see Table 1).

Other families of crop plants do host the fungi, but the degree to which they respond to the symbiosis is variable and often relates to the speed of root growth and development of root hairs by the plant and to soil conditions, particularly nutrient levels.

Table 1. Some examples of crops with different responsiveness to VAM

VAM responsivness	**Crop**
HIGH	faba beans linseed and linola peas chickpeas lentils medic vetch subclover lucerne citrus lettuce capsicum
MODERATE TO LOW	barley wheat oats
VERY LOW	rye buckwheat

A knowledge of of which crops are non-hosts and which are highly responsive could help improve crop productivity especially in soils with low nutrient availability. Ideally highly responsive crops should not follow non-hosts.

Lack of response does not mean that the beneficial fungi are absent. VAMs will continue to multiply in all host crops regardless of the crop's responsiveness. This can have positive benefits for a responsive crop later in the rotation

Table 1 provides a rough guide to crop responsiveness, but it is important to note that there will be variations with cultivar and soil conditions.

How are VAM affected by soil conditions?

To grow and reproduce, VAM fungi need living plants which are hosts. However, they are adapted to survive as 'resting stages' in most soil types and conditions around the world, including hot and dry, wet and frozen soils.

They are present in soils of all textures, from sandy soils to those with a high clay content and are also present at a wide range of soil pH.

A mixture of species is usually present, adapted to the local conditions.

The spores and infective root fragments can survive very well in hot conditions as **long as the soil is dry**, which is important for cropping in Mediterranean climates like South Australia. Spores will become active in moist conditions, but if host plants are absent, they will die. False breaks may reduce but certainly not eliminate colonisation when the crop finally gets going.

VAM do not use soil organic matter as a food source. Different species can associate with all host plant species (but not the non-hosts, of course). Host plants will provide sugars for the fungi and so help to maintain populations.

How does management influence VAM?

Rotations

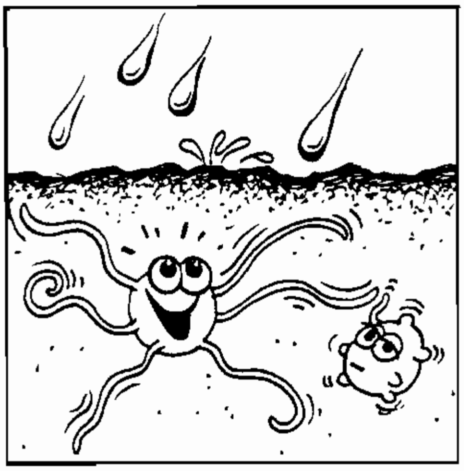
Rotations that include either long bare fallow (especially when the soil is wet) or non-hosts will reduce VAM populations.

The effect of bare fallow has been shown by research in Queensland, where 'Long Fallow Disorder' has been found to be caused by low populations of VAM.

This is because in warm moist soils without plants, the VAM spores germinate, but as they cannot find a plant, they die. If fallow persists for 12 months or longer, the VAM spores can effectively be wiped out.

In South Australia long fallows are not used and often the soil is dry in the summer, so germination does not occur and problems are much less likely.

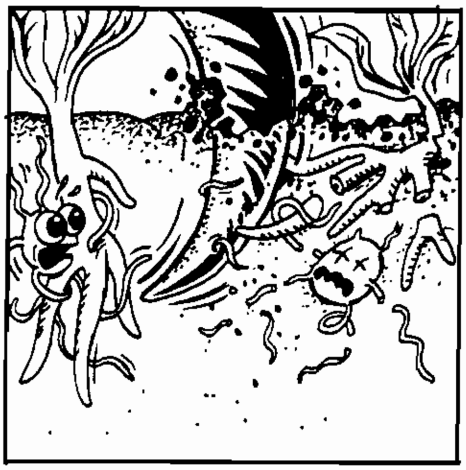
Non-host crops, like canola, also reduce VAM populations and the amount of VAM in the roots of the following crops. At present is seems that one year of canola will not create a major problem, but if several years of canola or mustards are grown for soil fumigation, then the VAM will be reduced, together with the disease organisms.

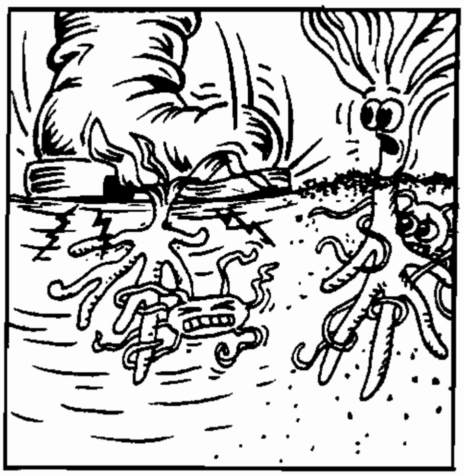


Long fallow - VAM spores germinate in moist soil. If host plant roots are not available the VAM will die.

Tillage

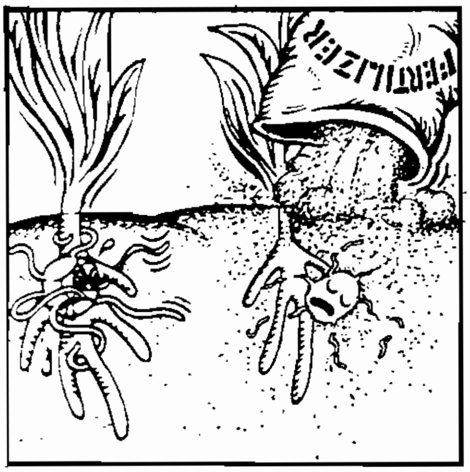
Conventional tillage and other soil disturbance has a negative impact on VAM function. It breaks up fungal threads in soil and destroys their connections with the plant so that they cannot work to increase uptake of nutrients.





Soil compaction

This not only reduces root growth, but reduces the benefits of VAM. Research is in progress to find out how the fungal threads grow through compacted soil and whether some fungi are able to do this better than others.



Fertiliser

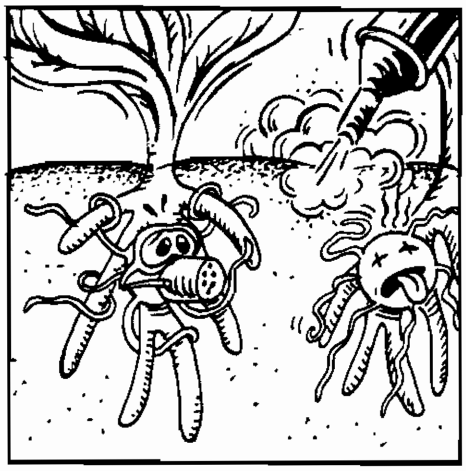
High fertiliser applications, especially phosphorus reduce the plant's need for VAM and can reduce the fungal populations too. The effect varies with the responsiveness of the crop. Wheat essentially loses its VAM partner when fertilisers are high, but peas, beans and many pasture legumes may still have the VAM and benefit from them, but to a lesser degree.

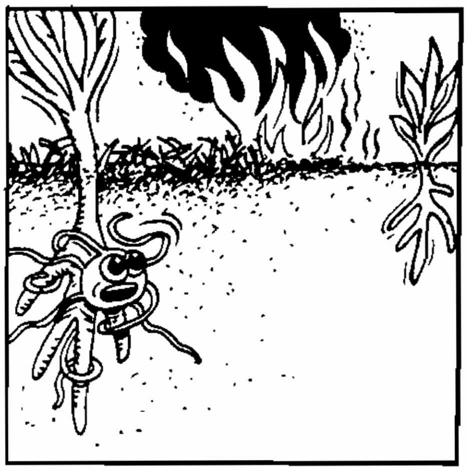
Pesticides and soil fumigants

Some fungicides, if they get into the soil, will reduce VAM populations.

Most herbicides do not seem to have a direct chemical effect on VAM, but they do kill the plants and therefore reduce the living food source of the VAM fungi.

Soil fumigants eliminate all soil biota, including VAM. This can be a problem in horticulture, especially if the crop is particularly responsive to VAM.





Stubble management

Retaining stubble will return nutrients to the soil and the VAM will help to take these directly to the plants. Stubble burning kills VAM, especially hot burns. Some research has shown that burning stubble from a peanut crop reduced the percentage of the root length of the next crop from 72% to 16%. Taking into account differences in the crop growth, this translated to a reduction of VAM-colonised roots from 12 metres per plant, to 1.5 metres per plant.

Organic management has been shown to increase VAM populations in the roots of crops.

Do VAM interact with other soil organisms?

VAMs compete with other members of the soil biota for soil nutrients and hence increase the competitive ability of their host plants.

They increase nodulation and nitrogen fixation in legumes by supplying the phosphate that is essential for effective nodulation.

VAM can increase the tolerance of plants to some diseases and pests by compensating for root damage and may even have direct negative effects on the disease-causing organisms themselves.

Some soil animals graze on VAM hyphae and spores, but unless the populations are very high and out of balance the grazing may actually help to keep the fungi young and vigorous and release nutrients from the dead hyphae.

Table 2: How can I make the most of VAM in my soils?

DO	**DON'T**
• Consider the role of VAM in different crops in the rotations. Is the crop a host or non-host, responsive or non-responsive? Will they build up soil populations?	• Grow biofumigation crops like, canola or mustards, for more than one year
• Include host plants in the rotations to build up populations, especially after a non-host, essential tillage or stubble burning	• Grow a highly responsive crop immediately after a non-host
• Limit non-hosts in rotations, especially before a very responsive crop	• Use conventional tillage, except where really necessary to reduce disease
• Adopt minimum tillage to avoid damage to the fungus	• Burn stubble every year. Occasional burns may be necessary

HERBICIDES AND LIFE IN THE SOIL

B[illegible] S R Gupta CSIRO Land & Water

Pesticides are an essential in modern agriculture. In Australia over $800 million is spent each year on pesticides, with 65% of this expenditure on herbicides.

Many herbicides are applied directly to the soil which has lead to questions about their impact on the soil biota - the Life in Soil.

A diverse range of organism types and species carry out one function

Soil biota consist of a diverse range of organisms; both flora (microorganisms) and fauna (animals). These organisms carry out key soil functions and are grouped by both body size and function (See figure 1) For example the function of nutrient cycling is carried out by microflora, e.g. bacteria, microfauna e.g. protozoa and mesofauna e.g. collembola (springtails).

All the organisms involved in a specific function are grouped and termed a functional group, eg. nitrification is carried out by nitrifying microorganisms.

Agronomic practices which interfere with specific organisms may reduce the output of a functional group but may not cause it to cease. However, this may result in a new population balance which could lead to plant pathogenic organisms becoming dominant.

An understanding of the impact of different herbicides on various soil functions will help farmers work in harmony with the soil biota and minimise the impact of herbicides on these functions.

Please note:

- The following information draws on Australian and international research.
- A majority of herbicide research is laboratory based. This is because field fluctuations in temperature and moisture and the variability in physical and chemical properties of soil may influence the soil organisms to a greater extent than the application of a pesticide. Direct transfer of results from lab research to field situations may not be appropriate.

Physical versus chemical weed control

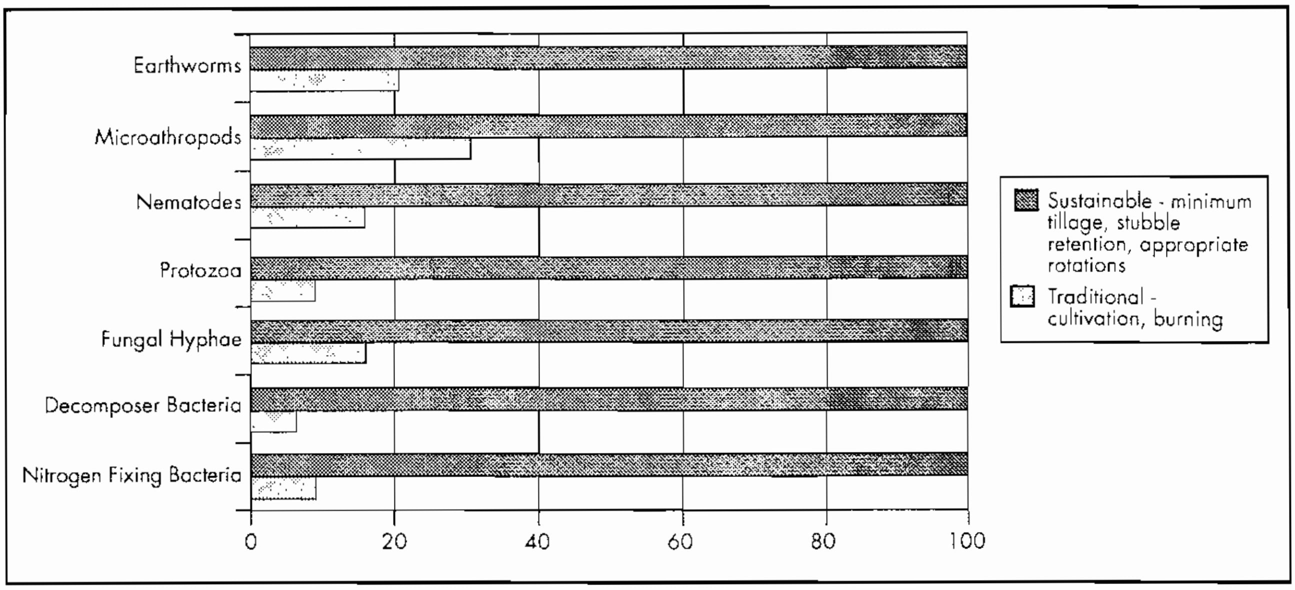
Appropriate use of herbicides could be less destructive to soil biota

The appropriate use of herbicides maybe less destructive to the soil environment and soil organisms than traditional weed control techniques of cultivation and stubble burning, (see graph 1)

For this to hold true the following management practices need to be in place:

- the retention of stubble/organic residues, a major carbon source for soil organisms
- low rates of chemical application
- a 'recovery period' for soil biota is allowed between herbicide applications
- repeated application of the same herbicide within a short period is avoided.

Graph 1: Impact of different farming methods on soil biota populations



Are all chemicals OK?

Appropriate chemical use with stubble retention may be better for soil biota than cultivation and burning but it does not mean that it is 'good' for soil biota. In general soil biota may be effected by herbicide applications either directly or indirectly. A direct effect is when the chemical kills the organism or inhibits its activity. Indirect effects include changes in soil temperature and moisture due to removal of weeds, the addition of weed residues with low C:N ratios and changes in the populations of predators and prey.

Details of the impact of some widely used agricultural herbicides are contained in table 3.

In many cases there are no definitive answers and only limited work has been carried out in Australia. Each herbicide needs to be considered separately.

Application of herbicides (such as SUs) should be avoided in situations where the crop is not robust and disease levels in soil are medium, especially in alkaline soils.

Table 3: A summary of findings for a range of chemicals tested in Australia or overseas.

Chemical and Group	**General Findings from Australian and International Research**
Sulfonylureas (SUs) Group B - Inhibitors of the enzyme acetolactate synthase - ALS inhibitors.	Reduced ability of microorganisms to grow up to six to eight weeks after application (microbial stress). May result in reduced nitrogen mineralisation. May cause increased incidence of plant diseases such as Rhizoctonia and Take-all. Some herbicides also reduce colonisation by mycorrhizal fungi. No information on long term effects.
Triazines Group C - Inhibitors of photosynthesis at photosystem II	Under long term field applications generally no effect on soil biota providing organic matter was continually returned to the soil. Short term effect on soil bacteria especially nitrogen fixers and those involved with nitrogen cycling. May increase the chances of some fungal, viral and nematode induced diseases.

Chemical and Group	**General Findings from Australian and International Research**
Trifluralin Group D - Inhibitors of Tubulin formation	No indication of long term effects. It has been found to interfere with legume/rhizobia symbiosis. May increase the chances of some fungal, viral and nematode induced diseases.
Hormonal Sprays Group I - Disrupters of plant cell growth	Negative effects have been recorded for nitrogen fixation by rhizobia and reduction in colonisation by mycorrhiza. Long term effects are variable and dependant on soil type and environment.
Paraquat Group L - Inhibitors of photosynthesis at photosystem I	Reduced rate of stubble decomposition when sprayed on to stubble rather than on to the soil containing stubble. Non-symbiotic nitrogen fixing bacteria are inhibited even at very low concentrations.
Glyphosate Group M - Inhibitors of EPSP	No indication of any long term effects. Nitrogen fixation by legumes has been shown to be reduced in some crops. Any negative effects are dependent on soil type.

In recent laboratory and field studies carried out in Australia a range of herbicides where applied as single applications at a range of rates. The following information details the key results.

Short term versus long term impact

Soils with a healthy biota may recover or compensate better from the short-term negative effects due to herbicide application.

The impact of a herbicide on soil biota may be reversible or irreversible. A reversible impact is one where levels of microbial growth are returned to 'normal' over a period of time after a singe application.

The duration of reversible impacts has been found to vary with:

- rate of application
- place of application - soil, stubble or plant
- type of herbicide
- frequency of application.

Results from both field and laboratory research have shown symptoms of microbial stress (reduced new microbial growth) even at recommended rates up to six to eight weeks following the application some herbicides eg. Glean®, Logran® (See table 4). These effects where found to be soil type dependent. For example, in sandy soils with low organic matter and low microbial activity the negative effects of these herbicides were found to be greater.

Table 4: The impact of different chemicals on microbial biomass (MB) and carbon dioxide production (MA)

Positive or no impact	**No impact on MB & positive impact on**	**Negative impact on MA both MA & MB**
Fusilade®	Ally®	Paraquat®
Roundup®	Glean®	Brodal®
	Hoegrass®	Logran®
	Logran®	Eclipse®

In similar experiments the herbicides Ally®, Hoegrass® and Paraquat® were applied directly on to soil without any stubble cover at two and five times the recommended rate. Micro organisms were found to be under stress and not functioning properly six weeks after the application. In most situations this low level of functioning continued up to nine weeks.

However when the chemical was applied directly to the soil or to growing plants the stress time for soil organisms was reduced.

Multiple application of the same or different herbicides within the six to eight week window is a common practice in broadacre agriculture. The research has shown that it takes six weeks for the microbial activity to return to normal. Consequently multiple applications before the end of the six to eight week recovery period would be expected to reduce soil biota function, especially if organic carbon food sources were also limited.

Stubble is home to 60% of the biota population therefore, applications to stubble will impact on a large proportion of the soil population.

The duration of this reduced biota function may be less significant than the timing. The majority of herbicides in broadacre cropping are applied around seeding. At germination the plant is at its most vulnerable as the root system is still developing. Reduction in biota functions such as nutrient release and disease suppression may reduce the early vigour of a crop or leave it more susceptible to root diseases. Application of another herbicide prior to the biota recovering from the first herbicide may accentuate the undesirable effects. More research work is needed in this area.

A recovery period of six to eight weeks should be allowed between applications of herbicides.

Impact on functions

Disease Transmission

Some herbicides were found to alter the balance between bacteria and fungi populations near the plant litter. For example, some SU herbicides and Hoegrass® increased the proportion of fungi near litter. This could result in the growth of opportunistic pathogenic organisms near the stubble increasing the chance of root diseases development.

Organic Matter Breakdown

Application of Ally® and Hoegrass® at twice the recommended rate reduced the ability of bacterial populations to use some of carbon substrates available from decomposing residues and near the growing root. This could result in a slower rate of stubble breakdown and associated nutrient mineralisation. Table 5 illustrates the significant reduction in cellulytic bacteria and fungi after herbicides have been applied.

Table 5: The number and percentage of microorganisms which can breakdown cellulose (a major part of straw) found near wheat straw after the application of herbicides.

	Bacteria		Fungi	
	population/g stubble	% remaining of control	population/g stubble	% remaining of control
Control	389000	100%	335000	100%
Ally®	3640	0.9%	6510	2%
Hoegrass®	38900	10%	313	0.09%

This work suggests Ally® is harder on bacteria and Hoegrass® is more detrimental to fungi.

Nutrient Cycling

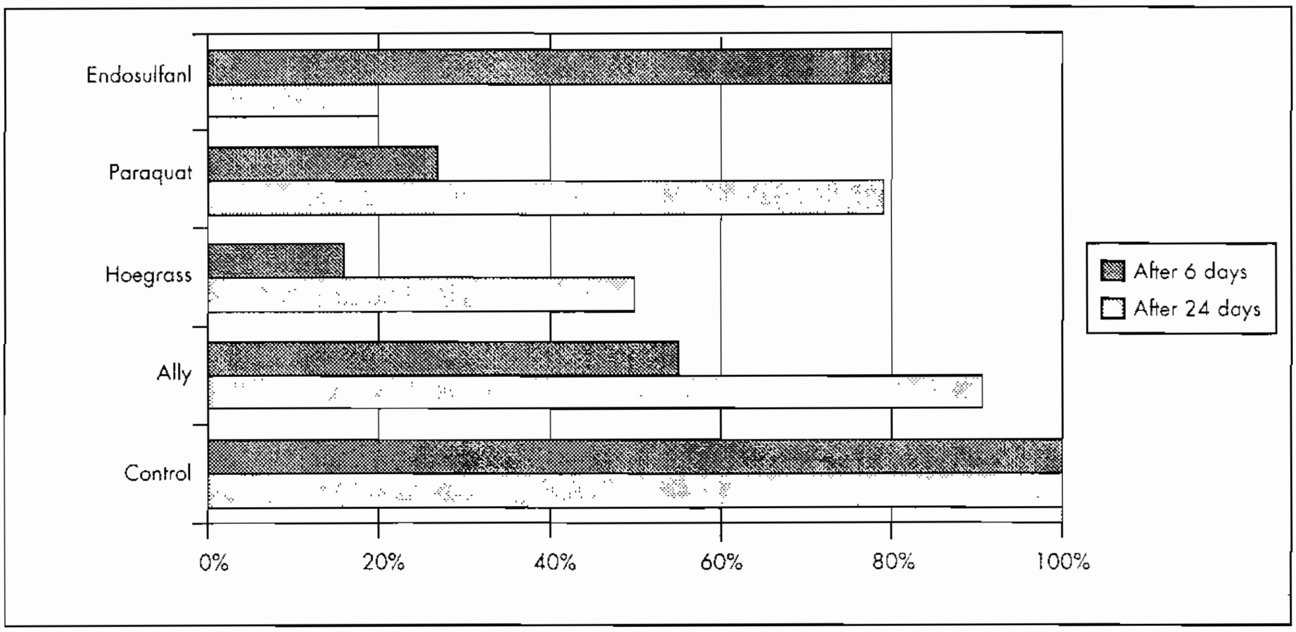
Avoid application of herbicides to legumes that may have negative effects on symbiotic nitrogen fixation

Other work has shown that the nitrifying bacteria, responsible for the transformation of ammonia nitrogen to plant available nitrate, are the most susceptible to herbicide applications.

Modified applications of fertilizer N may be appropriate to compensate for reduced N mineralisation during the first six to eight weeks following herbicide application.

Herbicide effect on mycorrhizal colonisation is two folded. Firstly herbicide effect the mycorrhizal fungi it self and secondly herbicides reduce root growth affecting the available root length for mycorrhizal colonisation.

Graph 2: Changes in levels of mineral nitrogen after application of a chemical to the soil.



Results are shown as a percentage of the mineral nitrogen available under the control. The larger percentage suggests high levels of mineralisation by soil organisms.

Pesticides as food

Microorganisms feed on simple carbon compounds and agrochemicals, therefore all pesticides, to a lesser or greater extent, can be used as a food source by the soil biota. Different chemicals will be used by different microbes, therefore populations of appropriate microbes must be present if the pesticide is to be degraded by microbes

It may take time for the populations of appropriate microbes to build-up. During this period these pesticides may harm other soil organisms and temporarily or permanently alter the balance of biota populations present in the soil.

Sulfonylureas have been found to persistent longer in alkaline soils. However, it is coming to light that in some alkaline soils sulfonylurea residues are becoming less of a problem. This is thought to be due to an increase in the number of organisms which breakdown these chemicals in an alkaline environment. Management practices that could lead to the build-up of these microbes are as yet unknown.

Microbial degradation of herbicides is an important method of breakdown. As the majority of microbes in southern Australian soils are located in the top 10 cm soil, movement of herbicides beyond this zone may result in long-term persistence of herbicides.

IN SEARCH OF A RECIPE FOR DISEASE SUPPRESSIVE SOIL

By Stephen Neate, CSIRO Land and Water

Take home messages:

- Disease suppressive soils are found throughout the world
- We have shown that suppression develops due to changes in soil biology
- Suppression identified in South Australia is against several disease organisms (pathogens) and exists in rotations
- Intensive cropping and increased carbon inputs are associated with the development of suppression.

For many years farmers and scientists have focused on the soil organisms that cause disease, the pathogens. However, more recently soil organisms which prevent disease have been put under the microscope and the search is on for farming practices which encourage the multiplication of disease suppressive organisms.

Soil organisms carry out a range of functions (see Figure 1). One of these functions is disease transmission and suppression. Suppression is restoring the balance between the soil organisms in the soil so the pathogens do not dominate.

A suppressive soil is one that, despite having conditions that favour the establishment of a disease forming organism, results in the pathogen:

- either not establishing,
- establishing but not producing disease,
- establishing and then declining

Suppression is not the elimination but the control of disease forming organisms. In agriculture we are trying to achieve a level of suppressiveness which prevents disease levels that cause economic loss. But suppression is relative - a soil may be suppressive, but disease at a lower level is still experienced.

Table 6: Advantages and disadvantages of controlling disease with suppresive soils

ADVANTAGES	DISADVANTAGES
• reduces the legal, environmental and public safety hazards of chemicals • should achieve control equal to the best currently available by other methods • can be used in organic or reduced pesticidez systems, thereby adding value to the product	• takes more intensive management and planning • may restrict flexibility in early years • requires new skills • disease control is not achieved immediately.

What makes a soil suppressive?

Warm, moist soils with high levels of carbon to nitrogen will have higher levels of microbial activity and relatively have a higher level of suppression

Naturally all soils have the capacity to suppress disease.

Microbial activity, which depends on soil moisture, temperature and the ratio of carbon to nitrogen, is the precursor to suppression. Table 7 illustrates the increase in soil organisms in suppressive soils compared to organism levels in non-suppressive soil at trial sites in Avon, South Australia.

Conditions that change biological activity or relationships between organisms can effect suppression.

Warm, moist soils with high levels of carbon to nitrogen will have higher levels of microbial activity and a relatively higher level of suppression.

Figure 7: Different levels of soil biota in suppressive and non-suppressive soil at Avon SA.

		Suppressive	**Non-suppressive**
Microbial Biomass (µg c/g)		250 - 500	200 - 450
Microbial Biomass near stubble	July	750 - 850	500 - 675
	August	600 - 700	400 - 525

The degree of suppression will also relate to the balance between disease-causing organisms and those organisms which feed on these pathogens. Figure 3 illustrates that the level of disease inoculum will vary from season to season. Consequently, a soil that is able to supress moderate levels of disease incolum may not be able to suppress disease in a year when large amounts of effective disease organisms have survived.

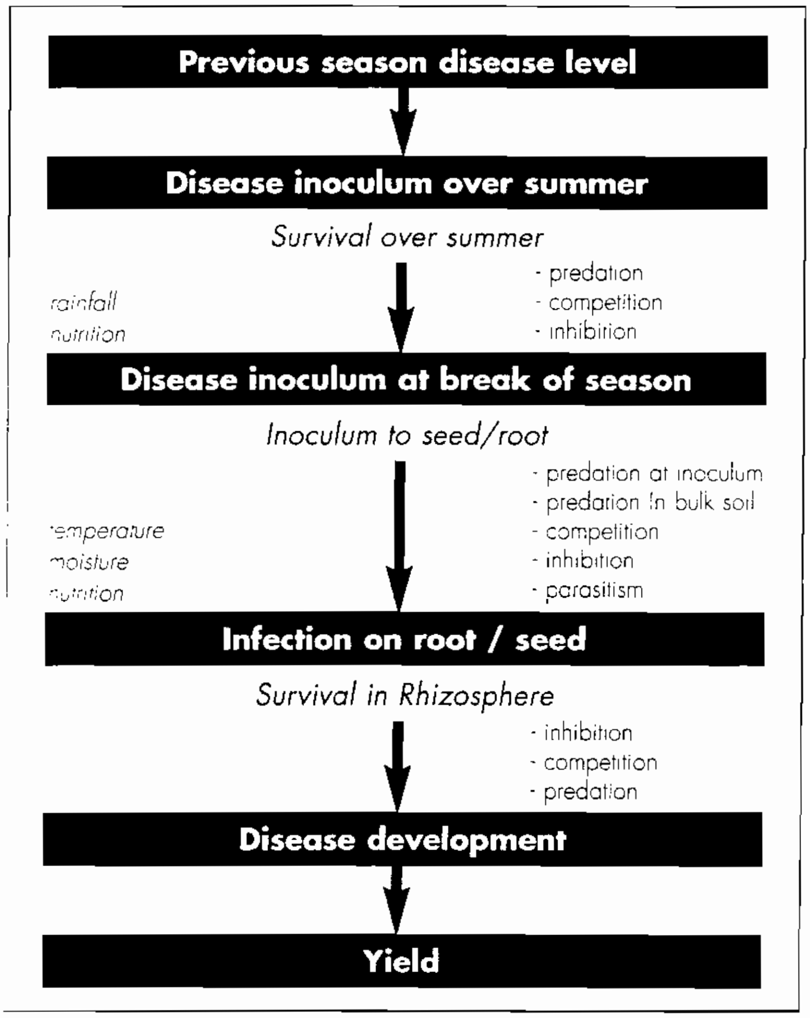


Figure 3: Survival and effectiveness of disease inoculum from one season to the next

(V Gupta)

Table 8: Disease capacity and stubble decomposition rates for the crowns / stubble recovered from field incubation which commenced in May.

Disease/ Decomposition level	Date of reading	Suppressive	Non-suppressive
Rhizoctonia solani	July	40 - 60 %	> 80 %
	August	< 20 %	> 60 %
Take-all (Ggt)	July	50 - 60 %	> 80 %
	August	30 %	> 70 %
Stubble breakdown % broken down	July	25 %	> 10 %
	12 months	70 %	35 %

Where soils were suppressive the disease level fell dramatically between July and August. At the same time rate of stubble breakdown, which is carried out by soil organisms, was found to be greater under suppressive soils.

Which diseases can be suppressed?

In Europe, suppressive soils have been found to suppress a single disease, for example Take-all decline. However, this suppression requires a monoculture to be maintained. Researchers in South Australia have found soils which are able to suppress a range of diseases under a range of crop types and which remain suppressive over different seasons.

Table 9: Disease in broad acre cropping which may or may not be suppressed.

Suppressed	Not suppressed	Unknown
Rhizoctonia bare patch Take-all Fusarium crown rot	Pythium root rot CCN	Pratylencus

What management practices improve suppression?

Maximising the return of crop residues to the soil has been found to increase microbial activity and turn a soil into a disease suppressive soil.

Stubble retention and minimising grazing have both been found to help maximise residue return.

Table 10: Case Histories - Management systems under which disease supression has been found to develope.

Case History 1:
Booborowie, South Australia

Soil type: Red Brown Earth

Annual rainfall: 425mm

Production System:

Prior to the development of suppression

- ley farming rotation system of wheat and barley crops with grassy pastures
- sheep - heavily grazed pastures

In the early 80's moved into

- more intensive cropping and stubble retention
- narrow sowing points to minimise soil disturbance
- 70kg DAP + Zn and 60kg Urea
- pastures sprayed year before for weed control, cultivated after the break with narrow sowing points and use of knockdown herbicides

Mid 90's - suppression recorded

Case History 2:
Lock, South Australia

Soil type: Grey Calcareous Sandy Loan

Annual rainfall: 400mm

Production System:

Non suppressive soil

- pasture/wheat/barley rotation
- one cultivation with narrow sowing points after the break
- Roundup three weeks before seeding
- Trifluralin before seeding

95kg 26:11 + Zn applied with the seed

Suppressive soil

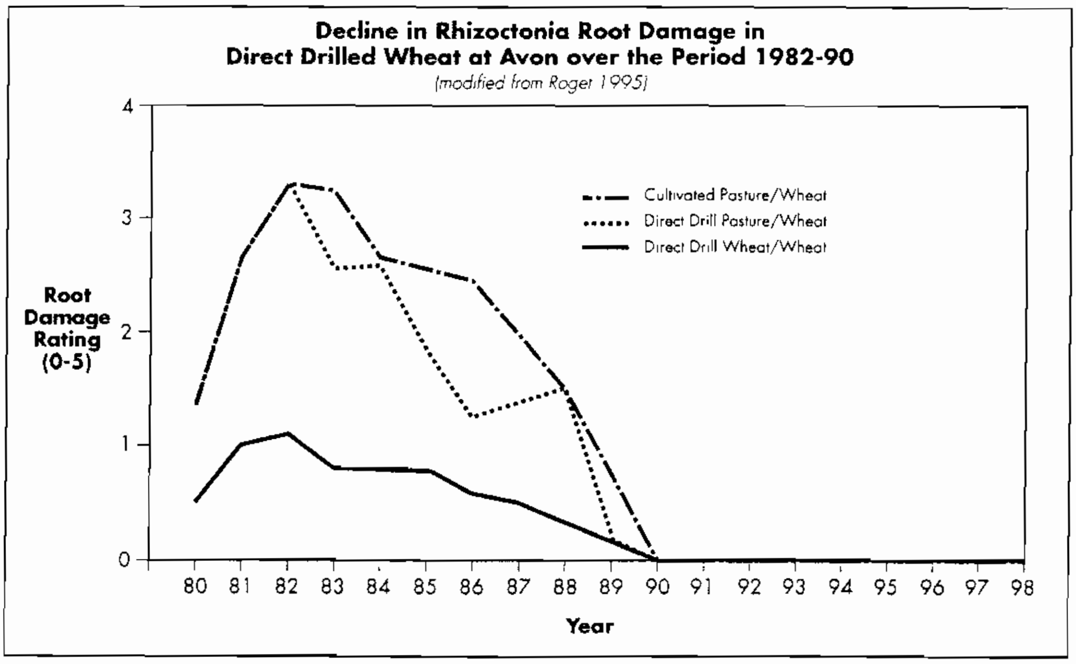
- continuous crop, wheat/barley/peas rotation
- one cultivation with narrow sowing points after the break
- Roundup three weeks before seeding
- Trifluralin before seeing

95kg 26:11 + Zn applied with the seed

How long does it take for a soil to become suppressive?

Suppression develops over a period of timing. The duration will depend on the conditions and the return of organic residues. At Avon disease suppression developed over ten years irrespective of rotation or tillage.

Graph 3:



FREE NITROGEN FROM THE AIR

Some facts, figures and rules of thumb

By Ross Ballard, SARDI.

Bacteria fix nitrogen

Legumes (clovers and lucerne) 'fix' nitrogen from the air into a form which can be used by the plant. This process is carried out by the bacteria, Rhizobia sp., which live in the nodules on the legume root.

Symbiosis

This is a symbiotic relationship, the plant receives nitrogen and the bacteria receive sugars.

Slow release fertiliser

Nitrogen fixed by a legume is organic nitrogen and acts like a slow release fertiliser. It becomes available to the plant as the plant residues are decomposed by other soil organisms. The process of converting organic nitrogen to the inorganic form which is available to plants is called mineralisation. Grasses, cereals, or the legume may take up this inorganic nitrogen.

"Rules of thumb"

Nitrogen fixation

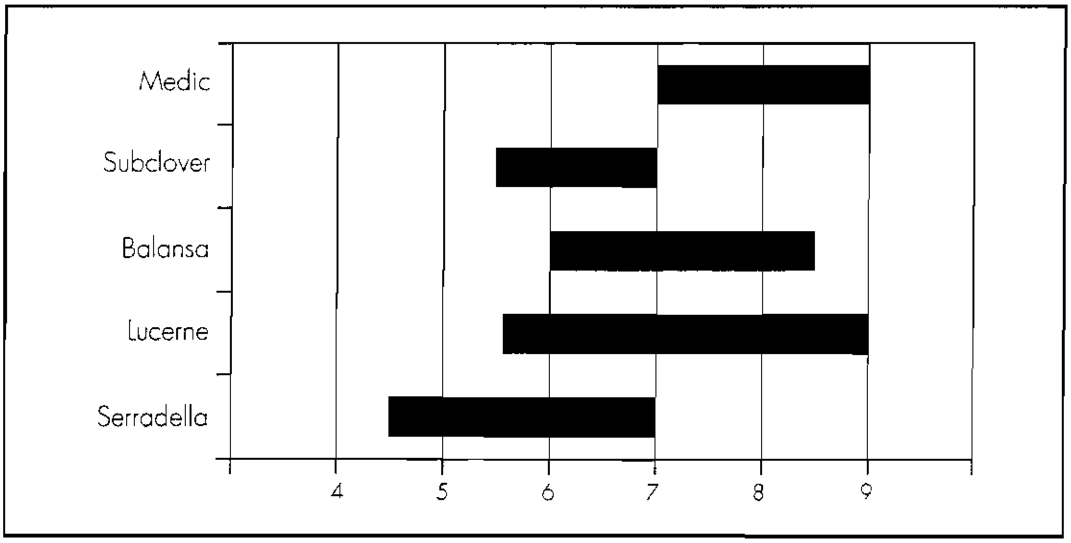
For each tonne of legume dry matter, 25kg of nitrogen is fixed.

A reasonable legume pasture may fix 125kg of nitrogen per hectare.

That is equivalent to 270kg of urea.

Different legumes fix and use different levels of nitrogen.

Graph 4: Prefered pH range for common pasture legumes



Soil texture and rainfall will also impact on growth

Horses for courses

Different legumes need different rhizobia. Clover rhizobia will not nodulate lucerne. Equally, lucerne rhizobia will not nodulate vetch. Hence, if you sow a new legume in a paddock, inoculation should be practiced.

Ensure you use the correct inoculant strain.

Rhizobial inoculants are alive

Remember that rhizobial inoculants contain living bacteria. They are fragile. Don't expose them to excessive temperatures or freeze them. Avoid mixing them with pesticides and fertilisers. Sow seed as soon as possible after inoculation, into a moist seedbed.

Rhizobia require warm moist soil conditions. They must be the correct species for the legume so that nitrogen fixation occurs.

Factors that will limit nitrogen fixation:

- Hot dry soil
- Incompatibility of rhizobium and plant
- Low pH
- High levels of nitrogen fertilizer.

Impact of pH

Soil pH can be the major limitation to a good symbiosis (see graph 4).

Nitrogen fixation by subclover may decline where soil pH falls below 5. Whilst there are often still rhizobia in the soil, their ability to nodulate the clover may be reduced. Liming to increase soil pH is the best solution.

Lucerne rhizobia are less tolerant of low pH. They are rarely found in soils where the pH is less than 6. Hence, it is absolutely essential that lucerne seed is inoculatedand lime pelleted at sowing. Liming to increase soil pH is also a good strategy.

"Rules of thumb"

Assessing nitrogen fixation

When

Plants are best assessed 8-10 weeks after germination.

Where

There should be at least 5 red nodules close to the top of the root system.

Red nodules

Sometimes the nodules needs to be cut to see the red colouration.

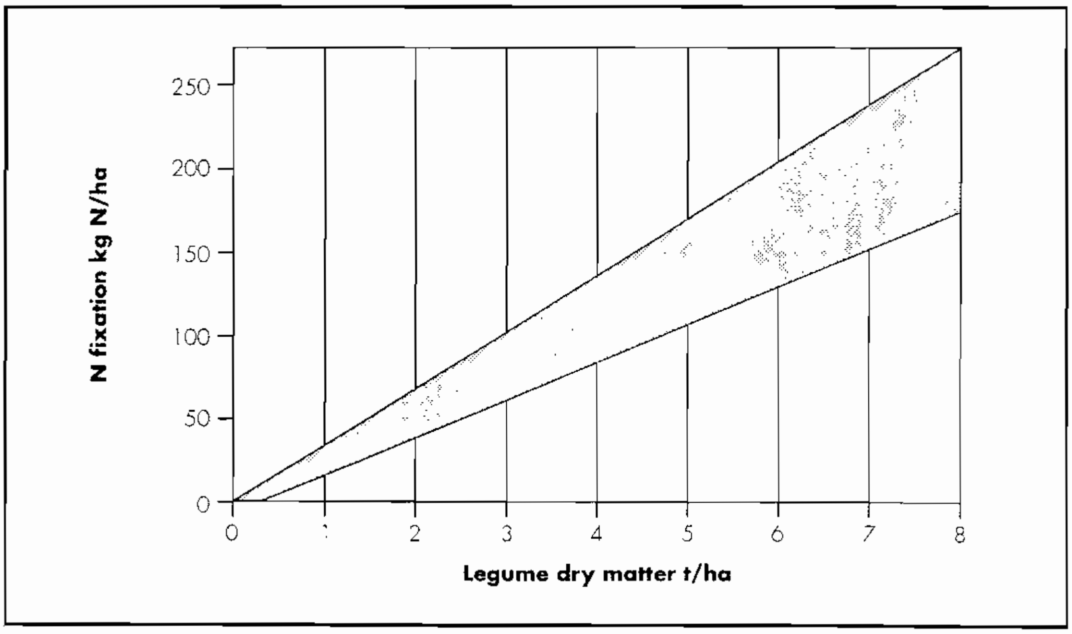
White nodules

Numerous white nodules scattered over the roots indicate the symbiosis is not fixing nitrogen.

Old nodule

Active nodules (red) may turn green as their n-fixation activity declines with age or plant stress. In subclover plants at flowering, it is common to observe that whilst the section of nodule close to the plant root is green, the nodule tip remains red. This red area of the nodule is still fixing nitrogen.

Graph 5: Approximate relationship between amounts of nitrogen fixed and legume dry matter production.



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