Building high carbon - low emission farming and grazing soils

A land managers guide

NORTH EAST DOWNS LANDCARE GROUP INC.

CARING FOR OUR COUNTRY

Reducing emissions and improving carbon levels in southern Queensland soils

A *Caring for our Country* project

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Introduction

The agriculture sector accounts for approximately 16% of Australias greenhouse gas emissions. Compared with the EU (10%) and the USA (5.5%), the agricultural industry in Australia is a very high (proportionately) emitter of greenhouse gases, and is this countrys second highest greenhouse gas emitter after energy production. Although the energy production sector is the largest emitter of carbon dioxide, the agriculture sector is Australia's largest source of methane and nitrous oxide emissions.

This guide was developed from the proceedings of a series of workshops presented to landholders across three NRM regions in southern Queensland during 2009, as well as information from associated relevant research papers. The workshops were the primary activities of a *Caring for our Country* project *Reducing emissions and building carbon levels in southern Queensland soils*. The workshops and associated field days were designed to provide information to farmers on the importance of soil carbon and how to build it, and how to reduced nitrous oxide emissions through improving nitrogen fertiliser use efficiency and intensive grazing management improvements.

The project did not intend to address the issue of methane emissions as we believe that there is still a long way to go with research into reducing the emission of this gas from livestock. However, there has been significant research into nitrous oxide emissions, and this will occupy a significant proportion of the guide.

The issue of carbon dioxide is looked on from an alternative viewpoint. There are now a considerable number of scientists and farmers who are looking at the potential for storing carbon in agricultural soils, rather than just seeing carbon dioxide as a threat. In the 200 years since European settlement, Australian soils have lost 50 — 80% of their soil carbon. Therefore anything we can do to build soil carbon will be a positive step towards more sustainable agricultural systems.

With the proposal of an emissions trading scheme that will eventually include agriculture, it is vital that farmers are informed of the issues, and how they will be affected. The immediate impact to farmers will be cost increases on inputs such as fuel, fertiliser and transport. However the long term impacts will very likely include an emissions cost for various land management practices based on the real or perceived emission rates for each practice. This means that farmers will need to adopt the most energy efficient and minimum emission practices in order to remain viable and competitive in an emissions trading environment.

There is however, a more important reason for farmers to adopt more efficient practices. All the evidence suggests that the effects of climate change will have a severe impact on Australian agriculture over the next 30 years, with increased temperatures, declining rainfall in many regions, and more intense and extreme weather conditions. The news is not all bad for farmers though. By adopting practices that reduce greenhouse gas emissions, farmers will not only become more resilient to climatic changes and extreme weather events, but they will also save money and become more profitable.

This project has the objective of informing farmers of the benefits and methodology of improving their soil carbon levels and reducing their nitrous oxide emissions through improved management practices, thus becoming more ‘greenhouse friendly’ and more profitable. To assist these two areas of the project a biological farming component has been introduced to showcase options that can enhance and improve soil biological activity, which is a vitally important aspect of soil health.

We hope that this booklet will be a useful reference to all farmers not only in in the southern Queensland region, but also to farmers in many other areas of Australia.

Peter Crawford

Project Manager

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Agriculture and greenhouse gas emissions

Australia emits approximately 550 million tonnes of greenhouse gases (in terms of carbon dioxide equivalent) per annum. The four types of greenhouse gas emissions are:

- ⇒ Carbon dioxide (CO_2)
- ⇒ Methane (CH_4)
- ⇒ Nitrous oxide (N_2O)
- ⇒ Hydroflourocarbons (HFCs) and polyflourocarbons (PFCs)

Greenhouse gases are measured and expressed as an equivalent of carbon dioxide, in terms of their global warming potential. Carbon dioxide, the most abundant greenhouse gas is given an equivalent of 1, while methane has an equivalent of 21, and nitrous oxide an equivalent of 310. In other words, although the actual quantities of these gases in the atmosphere are much lower than the quantity of carbon dioxide, methane is 21 times more harmful, and nitrous oxide is 310 times more harmful, than carbon dioxide. HFCs and PFCs are emitted in much smaller quantities and are not considered to be as significant as other gases.

The graph in figure 1 shows the proportions of greenhouse gases emitted for Australia during 2006, in terms of carbon dioxide equivalent (CO_2-e).

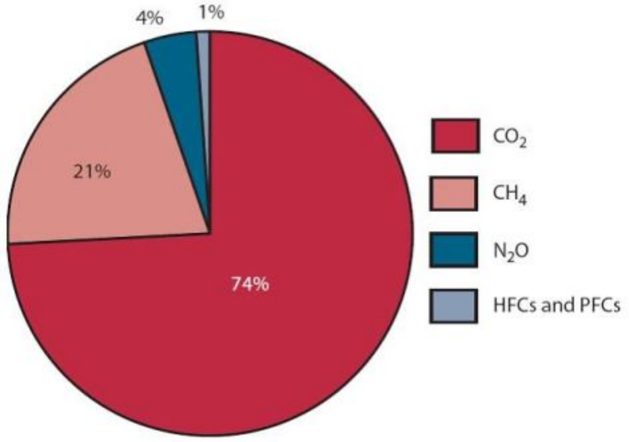

Figure1 : Contribution to total net CO_2-e emissions by gas, 2006 (source National Greenhouse Gas Inventory, 2006)

Agriculture emits approximately 16% of Australias total greenhouse gas emissions. Agricultural greenhouse gas emissions are:

- ⇒ Enteric fermentation in livestock – emissions associated with microbial fermentation during digestion of feed by ruminants and some non-ruminant domestic animals
- ⇒ Manure management – emissions associated with the decomposition of animal wastes while held in manure management systems
- ⇒ Rice cultivation – methane emissions from anaerobic decay of plant and other organic material when rice field are flooded
- ⇒ Agricultural soils – emissions associated with the application of fertilisers, crop residues and animal wastes to agricultural lands and the use of biological nitrogen fixing crops and pastures
- ⇒ Prescribed burning of savannas – emissions associated with the burning of tropical savannah and temperate grasslands for pasture management, fuel reduction, and prevention of wildfires
- ⇒ Field burning of agricultural residues – emissions from field burning of cereal and other crop stubble, and the emissions from burning sugar cane prior to harvest

Agriculture is responsible for almost 80% of Australias total nitrous oxide emissions and 60% of total methane emissions, making these gases a very high priority in terms of developing mitigating strategies and practices.

There are now well developed strategies and practices for reducing nitrous oxide emissions, and these will be covered later in the booklet.

Soil carbon – what it is, what it does, and how to build it

Soil organic matter and soil carbon

There is a direct relationship between soil organic matter (SOM) and soil carbon. SOM is the total of living and non-living organic material (plant and animal), as distinct from the mineral components of the soil. About 85% of SOM is made up of dead plant material, 10% from live plant roots, and 5% soil organisms. SOM content of the soil is expressed as a percentage of the soil by weight, and is a measure of soil organic carbon.

SOM is critical for soil health. The decomposition of SOM regulates the flow of energy and nutrients in the soil. SOM content is very important for the following reasons:

⇒ SOM provides food for microbes

⇒ SOM improves the physical structure of the soil and water infiltration

⇒ SOM increases water storage capability

⇒ SOM is a store for relatively available nutrients for plants

⇒ Approximately 5% of SOM is nitrogen, so a soil with 2.5% SOM will be holding around 2,800 kgs of reserve nitrogen per hectare (in the top 15 cm). Microbes transform a small amount of this nitrogen to plant-available form

⇒ The higher the organic matter content of the soil the greater is the amount of <u>all</u> nutrients that are held, not just nitrogen

Some soil tests give a reading for <u>soil organic carbon</u>, whilst others give a reading for <u>soil organic matter</u>. There is a simple relationship between soil organic matter and soil organic carbon.

Soil organic carbon % = organic matter % ÷ 1.73

There are three types of soil organic carbon:

1. Labile organic carbon – active and unstable, easily changed. Made up of living and non-living components that break down relatively quickly. Labile carbon can also be easily lost through management practices such as tillage.
2. Recalcitrant organic carbon – dominated by pieces of charcoal.
3. Humus – this is a stable, dark coloured group of organic compounds that are no longer recognisable as their previous forms. This type of carbon can remain stable in the soil for many years.

Of all these forms of soil carbon, humus is the most important in terms of soil health. Humus is made up of a number of organic compounds, but consists of about 58% carbon. Humus is essentially the organic material present in soil which has ceased breaking down.

Humus is a large source of minerals and nutrients in soil and it also plays a large role in controlling pH and cation exchange capacity in soils. It also makes soil more moisture retentive, yet better drained; improves soil structure; holds nutrients in a form that is easily absorbed by plants; insulates plant roots by keeping topsoil cooler in summer and warmer in winter, and acts as a buffer against extremes in soil pH through a complex exchange of electrically-charged particles in soil. Soil without humus is lifeless - it's dead soil.

Humus can hold up to four times its weight in water, so the more humus that can be added to the soil, the greater the water holding capacity of the soil.

The relationship between soil carbon and soil water holding capacity

For every 1% increase in soil carbon, up to 144,000 litres of water per hectare can be stored in the top 30 cm of the soil. In terms of rainfall, a 1% increase in soil carbon would enable the soil to store an extra 14.4 millimetres of rainfall before runoff. In production terms this could mean the difference between a poor or bumper crop.

The water infiltration and water holding capacity of soils is affected by other factors besides carbon content. Light sandy soils will have a higher infiltration rate than heavy clay soils, but heavy clay soils will be able to store a much greater amount of water, making the heavy clay soil a much preferred cropping soil.

However, soil carbon has a direct effect on soil structure and very low soil carbon levels in the heavy clay will make this soil more prone to sealing and hard setting, and reduce pore spaces. It will be more difficult to get water into a soil such as this. A soil with a high carbon level will have a more friable and open soil structure, making this soil much easier for water to infiltrate and be stored.

If this soil also has a high level of groundcover (stubble in a cropping situation and pasture biomass in a grazing system) then infiltration rates will be further enhanced.

Figure 2 : The well-grassed stock route on the left with a high organic matter content has allowed all the rainfall to soak in, whilst the bare cultivated block on the right has water pooling on the surface, which will eventually run off (photo P. Francis)

The importance of soil carbon to soil water holding capacity

The water use efficiency (WUE) of wheat varies from 5 to 20 kgs/ha of grain per 1 mm of rainfall, depending on soil type, fallow management and general soil management. For this exercise assume a WUE of 15 kgs/ha/mm.

1. *A wheat crop yielding 2.5 tonnes/ha would require approximately 170 mm of stored and in-crop rainfall. This equates to 1.7 million litres (1.7 megalitres) of water per hectare*
2. *A heavy clay soil with 1% organic carbon and a bulk density of 1.2 would be able to store about 100 mm of rainfall before runoff, depending on groundcover, soil structure and slope. With no in-crop rainfall, this soil should be able to produce a crop yielding about 1.5 tonnes per hectare*
3. *If this soil had an average soil carbon level of 3% to a depth of 30 cms, it could store an extra 288,000 litres of water per hectare, or the equivalent of 28 mm of rainfall – a total of 128 mm of stored water. With no in-crop rainfall this soil should be able to produce a crop yielding about 1.9 tonnes per hectare (an increase of 0.4 tonnes per hectare)*
4. *Assuming a wheat price of $200/tonne on-farm, the soil with 3% carbon is able to produce $80 per hectare more than the soil with 1% carbon. In a dry season this could be the difference between a profit and a loss*

A higher soil carbon level is like having money in the bank!

How carbon is stored in the soil

Photosynthesis is the key process for getting carbon into the soil. Photosynthesis is the process by which plants use the energy from sunlight to produce sugars, which are converted into adenosine triphosphate (ATP), a compound used for storing energy. The conversion of sunlight energy into usable chemical energy, is associated with the actions of the green pigment chlorophyll, which is stored in plant leaves.

The process of photosynthesis takes six molecules of water plus six molecules of carbon dioxide to produce one molecule of sugar plus six molecules of oxygen.

The chemical reaction for photosynthesis can be written as:

$$6CO_2 + 6H_2O + \text{sunlight} \longrightarrow C_6H_{12}O_6 + 6O_2$$

Some of the carbon stored as sugars is further refined and stored as humus, through the assistance of mycorrhizal fungi.

A simplified model of the soil carbon cycle is shown below.

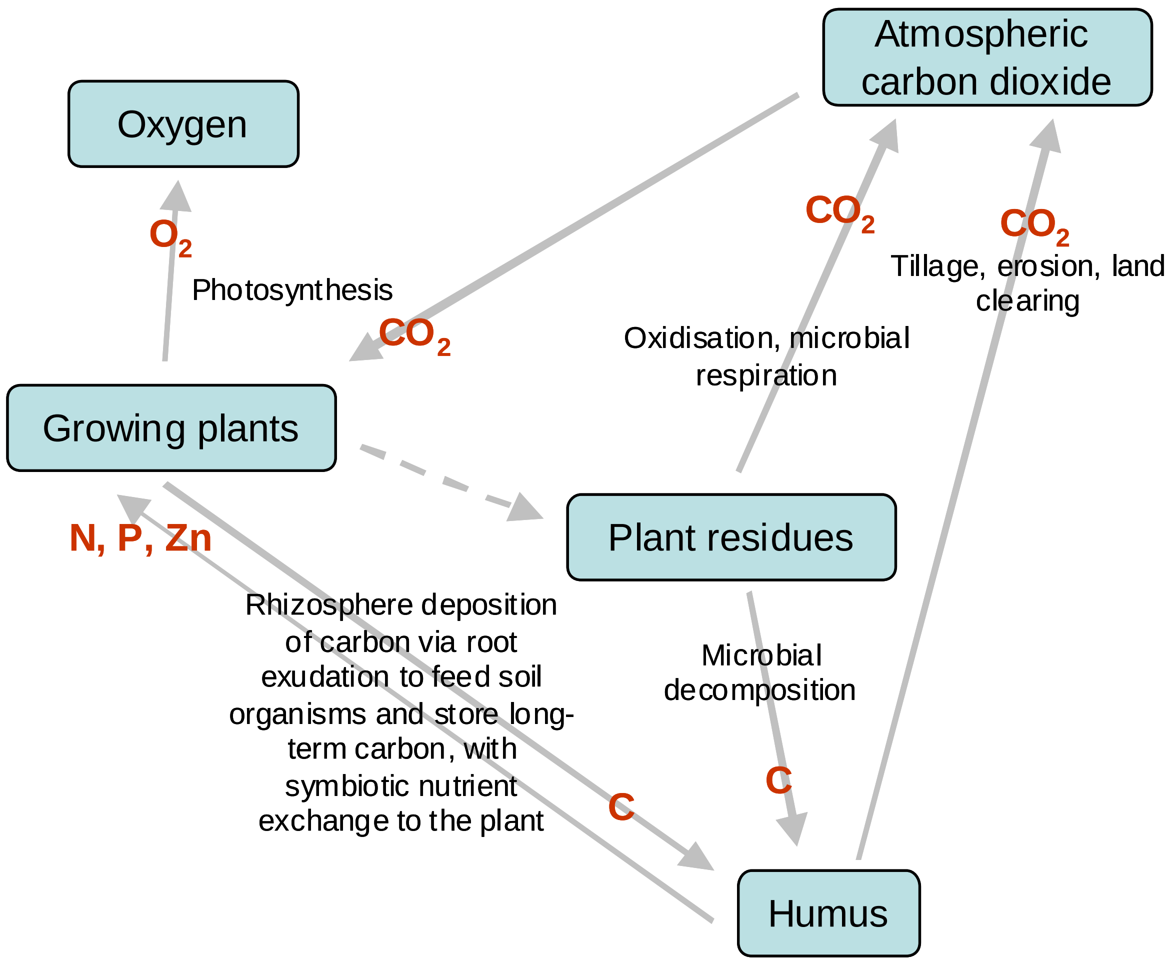

Figure 3 : Simplified soil carbon cycle (P. Crawford)

The relationship between mycorrhizal fungi and soil carbon

Mycorrhizal fungi are responsible for the transfer of nutrients (in particular nitrogen, phosphorous and zinc) into plant roots in exchange for soluble carbon extracted from the plant sugars. It is through this process that most soil carbon is stored in a long-term form in humus.

Mycorrhizal fungi attach themselves to plant roots and grow thread-like hyphae out into the surrounding soil. The fungi feed on sugars exuded by the plant, and in return the hyphae act like a greatly extended root system, siphoning nutrients back into the plant. This interaction is termed a 'symbiotic relationship'.

The interaction of mycorrhizal fungi with the plant root involves a substance called glomalin, which creates a carbon-rich sheath around the hyphae. Glomalin consists of 30 – 40% carbon, and according to some research it can account for a quarter of the carbon held in fertile soils.

Mycorrhizal fungi are found on the roots of about 80% of flowering plants, including grasses.

The diagram below is a simplification of the process of transferring plant sugars into stable soil carbon.

CO_2 ⟶ liquid carbon ⟶ soil ecosystem ⟶ solid carbon compounds

(from air) (in plants) (mycorrhyzal fungi) (in the soil)

Mycorrhizal fungi depend on a living and growing plant for their survival. This is further explained in a later section regarding the impacts of long fallowing on mycorrhizal fungi.

How much carbon can be stored in the soil?

If the bulk density of the soil is known, it is a simple matter to relate % soil carbon to tonnes of carbon per hectare. Most Australian soils have a bulk density of between 1.0 and 1.8 grams/cm3, or expressed in another way between 1.0 and 1.8 tonnes per cubic metre. In the following example we will assume that the bulk density is 1.4 grams/cm3 or 1.4 tonnes/per cubic metre. (Note: bulk density can vary with depth, so we will assume this is an average for the 0 to 30 cm range).

- ⇒ *Soil carbon (0 – 30 cm) = 2.0%*
- ⇒ *1 hectare = 10,000 square metres. At 30 cm (0.3 m) depth, the volume of soil in 1 hectare = 10,000 x 0.3 = 3,000 m^3*
- ⇒ *Weight of the soil with a bulk density of 1.4 tonnes/ m^3 (1.4 grams/cm^3) = 3,000 x 1.4 = 4,200 t/ha*

Therefore the amount of soil carbon stored in the top 30 cm of this soil is 4,200 x 2.0% = 84 t/ha

This example demonstrates just how much carbon is stored in the soil at even a relatively low percentage of soil organic carbon. It also demonstrates that if soil carbon levels were improved, a significant amount of carbon dioxide could be taken from the atmosphere and stored in the soil, for a small increase in soil carbon.

In the previous example, suppose the soil carbon was increased from 2.0% to 3.0% (an increase of 1%). The extra carbon stored in this soil to a depth of 30 cm would be 42 tonnes per hectare.

- ⇒ *Soil carbon percentage = 3.0%*
- ⇒ *Weight of the soil with a bulk density of 1.4 tonnes/m^3 (1.4 grams/cm^3) = 3,000 x 1.4 = 4,200 tonnes/ha*
- ⇒ *Therefore the amount of soil carbon stored in the top 30 cm of this soil = 4,200 x 3.0% =* ***126 tonnes/ha***

This is an <u>extra 42 tonnes</u> of carbon per hectare (126 – 84 = 42)

The potential for sequestration of carbon dioxide in soils

The ratio of carbon to carbon dioxide is 1:3.67. Therefore in the previous example, an increase of 1% in soil carbon would remove (sequester) **154 tonnes of carbon dioxide per hectare** from the atmosphere (42 tonnes C/ha x 3.67).

What does 'sequester' mean? Sequester means to remove, separate, segregate, or store

Assume that a land manager is implementing management practices that are increasing soil carbon over 1,000 hectares of country. Using the previous example, an increase of 1% soil carbon to a depth of 30 cm would sequester around **154,000 tonnes of carbon dioxide** from the atmosphere.

This amount of carbon sequestration could potentially offset all greenhouse gas emissions from agricultural activities on the property, depending on the rate of increase. An increase in soil carbon of 1% may take a very long time depending on management practices, but it is possible. However, the permanence of carbon sequestration in soil is still a matter of discussion, and more research will need to be carried out on this aspect of soil carbon building if it is to be included in future carbon pollution reduction schemes.

Some interesting facts about carbon sequestration

⇒ Soil is the largest source of carbon on planet earth

⇒ The worlds soils hold around three times as much carbon as the atmosphere, and over four times as much carbon as the worlds vegetation

⇒ Soil represents the largest potential carbon sink in which mankind has control

⇒ Sequestering carbon in the soil has an immediate impact on reducing atmospheric CO_2, compared to planting trees which can take years to have any real impact on CO_2 levels

Carbon may be stored at lower depths in the soil at similar levels to the top 30 cm. During her research Dr Christine Jones has measured the highest increase (from baseline levels) in soil carbon in the 30 to 60 cm depth in some soils under healthy and vigorous perennial grasses, although soil carbon levels were still higher in the top 30 cm. This demonstrates that a healthy perennial pasture is capable of fixing carbon at lower depths in the soil.

Carbon has been measured in significant levels down to depths of 1.1 metres. More research needs to be carried out to investigate soil carbon levels at various depths and under various land uses before any definitive assumptions can be made.

So how much carbon can soils potentially store? Researchers are unable to quantify this, and there is disagreement about the levels that could potentially be reached. However, many researchers agree that that the potential is significant.

Figure 4 : Mature trees are essential for habitat, but at this stage of maturity they are sequestering very little carbon dioxide (photo P. Crawford)

How carbon is lost from soils

Between 50% and 80% of carbon has been lost from Australian soils since European settlement. European farming methods that were introduced into the Australian landscape have been responsible for the majority of soil carbon decline.

The main agricultural activities that lead to losses of soil carbon are:

⇒ Cultivation – exposes soil carbon and organic matter leading to accelerated organic matter decomposition and soil erosion

⇒ Burning of stubble, removal of plant residues as hay – reduces the amount of organic material returning to the soil

⇒ Fallowing – traditional long fallowing leaves soil bare and exposed, resulting from increased cultivation activities for weed control

⇒ Overgrazing – leaves the soil bare, and results in decreased root biomass beneath the soil, as the volume of root biomass is directly related to the biomass above the ground

In real terms, soil carbon has fallen by at least 3% from original levels over the past 50 to 100 years. This has resulted in a serious decline in most agricultural soils ability to capture and retain water, and provide nutrients for crops and grasslands.

The two graphs in figure 5 demonstrate the decline in soil carbon under various land uses. The soil in graph (a) is a cane farm soil at Nambour (Qld.) and the soil in graph (b) is a mixed farming soil at Kingaroy (Qld.). Both soils are rainforest soils, and in each case the carbon in the rainforest remnant soil is much higher (from 0 – 40 cm) than in the soils of any of the current landuses. Of the three landuses on these two soils, the pasture has been the least destructive of soil carbon, but even under this land use soil carbon levels have declined significantly.

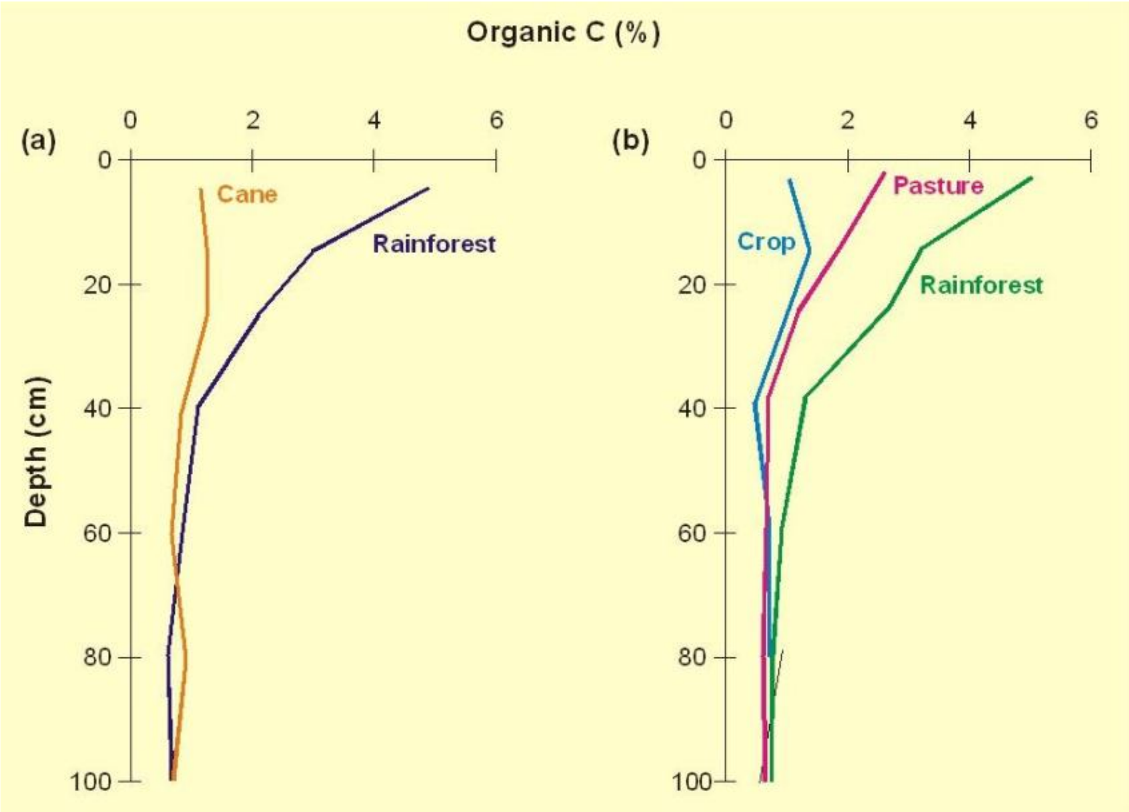

Figure 5 : Decline in soil carbon levels over a 30 year period under various landuses (source P. Moody, Qld. Dept. Natural Resources and Water)

Reducing soil carbon loss

Traditional or conventional agricultural systems generally cause a gradual reduction in soil carbon levels from the levels under the original vegetation, as shown in the graphs in figure 5. Soil carbon is lost through the decomposition and conversion of carbon in plant residues and soil humus into carbon dioxide.

To reduce the rate of loss of soil carbon, the cause of the loss needs to be addressed. In all cases, soil carbon loss is linked to and exacerbated by a lack of groundcover, whether in a farming or a grazing situation. Therefore any practice that retains or enhances groundcover will have an effect on reducing soil carbon losses.

Eliminate or reduce cultivation

A long-term trial was conducted by Qld. Department of Primary Industries at Hermitage Research Station at Warwick (Qld.) to compare various cropping practices, in terms of yield, greenhouse gas emissions and soil carbon. The trial was conducted over a 33 year period from 1968 to 2001. The trials were based on variations of conventional tillage compared with zero tillage.

Soil carbon was measured annually in the 0 – 10 cm range. The zero till practices increased soil carbon at an average of 1.8 tonnes per hectare over the 33 years, or approximately 55 kgs/ha/year. Although this only represents an increase of 0.18% to the original 2.0% over 33 years, it compares favourably to a decrease in soil carbon in all the other treatments, especially the treatments without nitrogen fertiliser.

The additional benefits of zero tillage of increased water infiltration and reduced soil erosion make this cropping system much more sustainable and productive than cultivation, which have been the main reasons for the adoption of this practice over the past couple of decades.

Three important findings from the Hermitage trials

1. *Soil carbon is destroyed by cultivation.*
2. *Even under the best managed zero tillage system with retained stubble and a good fertiliser regime, it is not easy to build soil carbon levels, although a well managed zero tillage system should at least prevent a further decline in soil carbon.*
3. *The trial results showed that added nitrogen fertiliser contributed significantly to soil carbon building. Good agronomy including good fertility is needed to maximise plant health and vigorous growth, which will contribute to building soil carbon.*

Eliminate long fallows where possible

Long fallows are used to increase the water storage in the soil for the next crop. Long fallows are also used to change to another crop type in a rotation, for example from a winter crop to a summer crop.

Traditional long fallows result in long periods with the soil bare of all cover, caused by numerous tillage operations. In a zero tillage situation this is not as pronounced, but ground cover is still reduced over the period of a long fallow.

In periods of drought, which has been the case over much of eastern Australia since 1998, ground cover has been further reduced as a result of poor crop yields. This is exacerbated by baling of crop residues by farmers to try and make up lost income. Whilst this is understandable, the soil carbon impacts are real.

The impact of long fallows on soil organisms is particularly important, especially the impact on mycorrhiza fungi. Mycorrhiza need plant roots to survive, and if there is a period where there are no growing plants, the mycorrhiza will die out.

The combination of mycorrhiza fungi and plant roots is also known as vesicular-arbuscular-mycorrhiza, or VAM. Research carried out by the Qld. Department of Primary Industries in the late 1990s identified very low VAM levels following a long fallow as the major cause of poor growth rates and yield of the subsequent crop, even with increased plant available water. The research findings put this down to the decreased availability of nutrients, particularly phosphorous and zinc, because of the low VAM levels. This effect is known as “long fallow disorder”.

The research found that some plant species have more dependence on VAM than others. This is outlined in the table 1.

Table 1 : Mycorrhiza dependency of various crops (source QDPI&F)

MYCORRHIZA DEPENDANCY	WINTER CROPS	SUMMER CROPS
Very high	Linseed Faba bean	Cotton Maize Pigeon pea
High	Chickpea	Sunflower Soybean Navy bean Mung bean Sorghum
Low	Field peas Oats Wheat Triticale	
Very low	Barley	
Independent	Canola Lupins	

Maintain and conserve crop residues

Burning crop stubbles has virtually ceased in most agricultural regions in Australia since 1990. Stubble retention was promoted initially as a means of reducing erosion and improving water infiltration for production benefits, and all the research carried out over the past 30 years has backed this up. Only in recent years has the soil carbon benefit of stubble retention been seen to be important.

In some areas there is a move back to burning crop residues as a means of overcoming herbicide resistance of specific weeds, such as annual ryegrass. In this situation it would be far more preferable to introduce a pasture phase or crop rotations to overcome herbicide resistance rather than to burn crop residues.

The removal of crop residues as hay is also very common in some areas. There has been an increase in baling crop residues as an income source during drought times. However, the removal of any organic matter source will have a detrimental impact on the maintenance of soil carbon levels.

Figure 6 : Removal of crop residues as hay has an impact on soil carbon (photo P. Crawford)

Reduce the impacts of overgrazing

Grasses that are heavily grazed will eventually die out, to be replaced by less desirable species. The reason for this is that the plant root system is basically a reflection of the plant biomass above the ground. If grasses are overgrazed, the root system shrinks to reflect the above-ground plant, and will not be able to access moisture and nutrients to support new growth. When a grass plant is heavily grazed (ie most the leaf area removed) the roots respond by sending carbon to the crown to produce new leaves, leaving the roots pruned and significantly less in volume than before grazing.

As a healthy and vigorous root system is vital for building soil carbon, overgrazing can lead to soil carbon decline as well as the loss of the most palatable species in the paddock.

Figure 7 : Root systems of grasses are a reflection of the amount of biomass above ground (photo C. Jones)

Building soil carbon

According to Dr Christine Jones any farming practice that improves soil structure will build soil carbon. Soil microbes play a very important role in building and maintaining soil structure. Glues and gums from fungal hyphae in the soil rhizosphere enable the formation of peds or lumps (able to be seen by the naked eye). The presence of these aggregates creates macropores (spaces between the aggregates) which markedly improves the infiltration of water.

Aggregates made from microbial substances are continually breaking down and rebuilding. An ongoing supply of energy in the form of carbon from actively growing plant roots will maintain soil structure, as seen in a healthy perennial pasture. If soils are left without green groundcover for long periods they can become compacted and susceptible to erosion.

Under conventional cropping or grazing on annual pastures the stimulatory exudates produced by short lived species are negated by bare earth at other times of the year. The result is a decline in levels of soil carbon, soil structure and soil function.

The importance of green plants

The relationship of photosynthesis to soil carbon was explained previously. Only green plants photosynthesise, so any period without actively growing green plants in the soil will impact on soil microbe and soil carbon levels. Soil carbon building requires green plants and soil cover for as much of the year as possible.

In many agricultural enterprises using current or traditional management practices it is simply not possible to have green plants growing for much of the year. However in virtually all situations it is possible to improve the level of groundcover, so increasing the level of permanent groundcover should be the primary objective of land managers in all agricultural enterprises.

Building soil carbon in grazing situations

A well managed native perennial pasture will have a wide range of plant species. In southern Australia rainfall can occur in most months of the year, with peak rainfall months in either winter or summer depending on latitude. In a diverse pasture there will be certain species that will respond to rainfall during certain months, so there is always the potential for at least some species in the pasture to be growing in most months of the year.

Poorly managed grazing can result in the elimination of a large number of palatable species, resulting in a few remaining less palatable species that in most cases only respond to rainfall at specific times during the year. This will result in a totally dormant pasture for at least part of the year, irrespective of rainfall.

The key to maintaining a healthy pasture is to adhere to a safe utilisation rate. A safe utilisation rate is the maximum rate of average annual use of the pasture biomass consistent with maintaining or encouraging good pasture condition. The Queensland DPI&F have developed recommended safe utilisation rates for a range of land types in Queensland, and for most land types the recommended utilisation rates are generally less than 40% of total pasture quantity. The recommended utilisation rate for some poorer land types is as low as 20%.

An alternative to following the safe utilisation rate is the one-third rule, which basically states that animals should only be allowed to consume one third of the pasture biomass during a grazing event. Whichever method of pasture utilisation is used, simple pasture monitoring activities will enable landholders to assess their pasture quantities and species diversity. Landholders should contact their relevant state agencies for advice on setting up a pasture monitoring program.

To maintain a healthy and diverse pasture, a good rule to follow is the 'one-third' rule:

- ⇒ *Animals eat 1/3 of the pasture (by weight)*
- ⇒ *1/3 is trampled, which is necessary for cycling of nutrients and the build up of organic matter*
- ⇒ *The plant retains 1/3 to maintain structure and root mass*

Under a set stocked grazing system, there is no control over pasture utilisation, as stock will tend to heavily graze more favourable areas in the paddock and avoid less favourable areas.

Dominance by large and medium perennial tussock grasses underpins the ecological health of native pastures. Large perennial tussock grasses can effectively capture organic matter and nutrients moving over the soil surface, and they incorporate more biomass (roots and litter) into the soil than small annual species.

To maintain healthy pastures they should be grazed conservatively, and spelled early in the growing season. This will allow grass tussocks to build up energy reserves and nutrients, which are likely to be depleted after extended dry periods. The rest period needs to be long enough to allow the plants to set seed.

The potential for improving soil carbon levels in a grazing situation will depend wholly on the type of grazing system being used, and the length of rest periods. Dr Christine Jones has measured soil carbon levels in well managed perennial pastures, and found that in some cases soil carbon was higher than in adjoining natural bushland.

Figure 8 : Overgrazing has left this hillside totally devoid of groundcover and exposed to erosion and high soil carbon losses (photo P. Crawford)

Building soil carbon in cropping situations

The Qld. Department of Primary Industries Hermitage Research Station trials demonstrated the value of zero tillage to maintaining soil carbon levels, and the also the possibility of building soil carbon under this type of cropping system. Similar trials carried out by the NSW DPI at Wagga Wagga for 19 years showed soil organic carbon under zero tillage plots measured 2.5% compared to 1.5% in the plots that had the stubble burnt and three tillage passes.

Under continuous cropping zero tillage, soil carbon was still lost, although at a lower rate than the conventional cropping plots. In the zero tillage wheat and sub-clover rotation, the soil organic carbon actually increased at a rate of 185 kgs/ha/year.

It needs to be recognised that zero tillage techniques have improved dramatically since the establishment of these trials, and it may be possible to improve on the results of these trials. However there are significant barriers to building soil carbon under even the best zero tillage system.

1. Chemically-based zero tillage broadacre continuous cropping does not provide the best environment for high levels of sequestration of humified soil carbon. There are concerns regarding the possible detrimental effect of herbicides and chemical fertilisers on soil biology, reducing the potential for active soil carbon sequestration.

2. Current best practice zero tillage involves minimal soil disturbance (especially with disc openers) leaving the stubble standing, which is advocated as the best method for reducing soil erosion potential. However standing crop stubble is exposed to the air, resulting in oxidisation to the atmosphere of much of the carbon contained by it. Standing stubble also reduces the availability of crop residues to microbes for breaking down and storing the carbon in the soil. This poses a dilemma for zero tillage practitioners, with issues arising from an operation to lay the stubble onto the soil, including soil compaction and a reduction in protection from erosion.

3. Zero tillage farming results in a total absence of growing plants during the fallow period, resulting in a decline in the mycorrhiza population.

To get the best carbon potential from a zero tillage farming system, farmers should consider:

⇒ *Putting standing stubble on the ground, using an implement such as a prickle chain or slasher*

⇒ *Rotating crops, and including grain legumes in the rotation*

⇒ *Introducing livestock and incorporating a pasture phase where it is practical*

Figure 9 : Chickpeas double cropped into sorghum stubble is a good option for a crop rotation in northern cropping areas, and is also a good solution to the problems associated with a long fallow (Photo P. Crawford)

Improving productivity and building soil carbon with pasture cropping

Pasture cropping is the practice of zero tillage planting of an annual grain or fodder crop into dormant perennial pasture. The crop grows symbiotically with the existing pastures with real and advantageous benefits for both the pasture and the crop.

This idea was initiated in the early 1990s by Colin Seis and Daryl Cluff from Gulgong NSW, and since that time Colin has spent much of his time perfecting this technique. The development of the pasture cropping system over the years has led to many different types of winter and summer growing crops being grown without destroying the perennial pasture base.

In a pasture dominated by C4 (summer growing) grass species the pasture will not compete with a sown winter crop, as the pasture is entering a dormant phase as the winter crop is growing. In a C3 (predominantly winter growing) pasture, it may be necessary to shut the pasture down with a light chemical application, or use a summer growing crop.

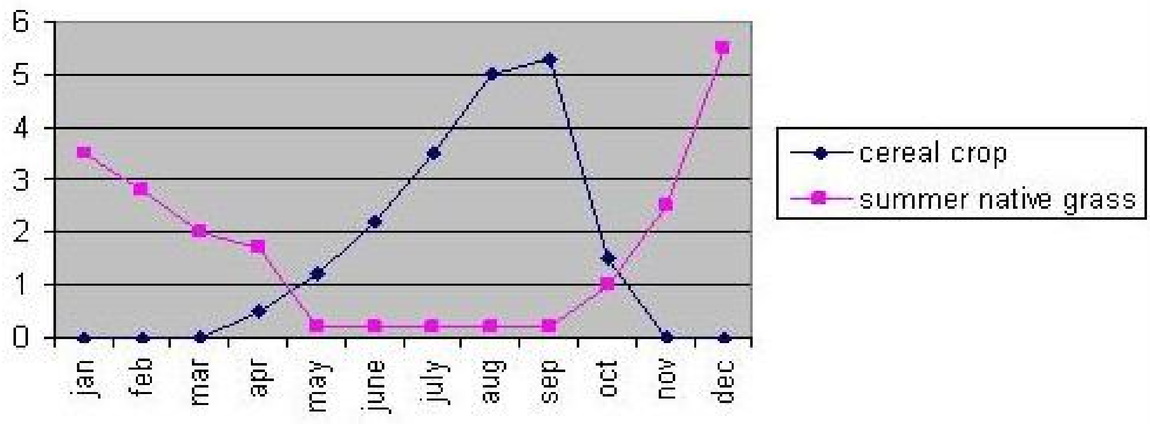

Figure 10 : Growth chart showing how the winter cereal crop does not compete with a summer growing perennial pasture in a pasture cropping paddock (source Colin Seis)

Pasture cropping is much more than just a planting technique. Pasture cropping is the combining of cropping and grazing into one land management system where each benefits the other. Roughing cereals, particularly oats, into pasture paddocks has been a technique used by Australian farmers for decades to provide early season fodder for livestock. Yet rarely do these crops go through to grain harvest unless the season is particularly favorable. Pasture cropping is actually an optimisation of the system that allows a fodder supply plus a grain harvest from cereals sown into native pasture country through better management of both the crop and the pasture component.

It has been found that sowing a crop in this manner stimulates perennial grass seedlings to grow in numbers and diversity giving considerably more tonnes per hectare of plant growth. This produces more stock feed after the crop is harvested and totally eliminates the need to re-sow pastures into the cropped areas. Traditional cropping methods require that all vegetation is killed prior to sowing the crop and while the crop is growing.

Figure 11 : Oats sown into a dormant perennial native pasture (photo Colin Seis)

Dr Christine Jones believes that pasture cropping has a huge potential for building soil carbon because of the increased photosynthesis activity. In fact pasture cropping can result in higher rates of soil building than under a perennial pasture alone. This may be due to the year-round transfer of soluble carbon to the root zone and maintenance of the humification process in the non-growth period of the perennial pasture.

A permanent cover of perennial plants provides an on-going source of soluble carbon for the soil ecosystem, buffers soil temperatures, reduces weeds, prevents erosion, improves infiltration, enhances aggregate stability, and improves structure. This is an ideal basis for establishment of an annual crop into the pasture.

Pasture cropping has been proven to be extremely useful in rejuvenating a worn out or degraded perennial pasture. Whether it is the slight soil disturbance caused by planting the grain crop, increased microbial activity from the roots of the grain crop, or other factors yet to be determined, perennial grass recruitment from seeds is often a result. This was demonstrated in the case of a Central Queensland landholder who took up the advice of Christine Jones and Colin Seis, and planted a summer-growing millet crop into a degraded pasture paddock. The result was a very productive perennial pasture one year later (figure 12).

Paddock prior to planting a millet crop

Millet crop 2 months after planting

Perennial grass seedlings establishing in furrows

Perennial pasture 12 months after the millet

Figure 12 : Rejuvenation of a Central Qld. pasture paddock with pasture cropping (photos C. Jones)

One of the main advantages of pasture cropping for grain is the immediate supply of high quality stockfeed after harvest of the grain crop. Colin Seis generally plants oats for grain into his pastures, but if the season turns dry there is still the option of grazing. When left for grain, the grain crop will tend to shade out the early spring growth of the perennial pasture, and when the grain is taken off at harvest the reduced stubble cover allows the pasture to take off after rainfall. The grain crop residue also acts as a mulch for the pasture, protecting the soil from erosion and ensuring a high infiltration of rainfall.

Main points to consider with pasture cropping:

- ⇒ *Never plough the pasture – use a zero till planter that creates as minimal disturbance as possible*
- ⇒ *Never kill perennial grass species*
- ⇒ *Perennial grasses can be native or introduced species*
- ⇒ *Treat the grain crop <u>as a crop</u> – that is, use some fertiliser when and if it is needed*
- ⇒ *Weeds can be managed by creating large quantities of thick litter by using <u>good</u> grazing management of livestock*
- ⇒ *Although the aim should be to reduce or eliminate chemicals, sometimes it may be necessary to spray top (but not kill) the pasture prior to planting the grain crop, and to control broadleaf weeds in the grain crop*
- ⇒ *Pasture cropping has been adopted by over 2,000 farmers in all southern states in Australia, with successes in all regions south of the Tropic of Capricorn. Depending on latitude, there will be a suitable pasture/annual crop mix to suit most situations*

Improving soil biological activity – towards a more natural farming system

The Soil Health Knowledge Bank website describes a healthy soil as '*a soil that is productive and easy to manage under the intended land use. It has chemical, biological and physical properties that promote the health of plants, animals and humans and contributes to profitable farming systems and growing regional economies*'.

There has been a huge body of research carried out on the chemical and physical properties of soils, but the biological functions of soil has only recently being recognised as a crucial component of overall soil health.

Former CSIRO farming systems agronomist Dr Maarten Stapper is passionate about discovering and using the power of nature in food production systems – and the connections between soil biology, soil health, and the overall functioning of agro-ecosystems, and he sees many opportunities for Australian agriculture to reverse soil degradation and regenerate soils. These opportunities rely on an improved knowledge and subsequent management of soil biological processes.

Plants depend on beneficial soil organisms to protect them from pathogens, to help them obtain nutrients from the soil, and to break down toxic compounds that could inhibit growth. Soil organisms create a living, dynamic system that needs to be understood and managed properly for best plant growth. If the balance of micro-organisms is wrong, fertilisers and pesticides can't help recover plant vigour. Understanding soil health requires knowing which organisms occur, which ones are working, how many are present and whether they are the right type for the desired plants.

Soil contains a huge number and diversity of organisms. It is often quoted that the weight of soil organisms under a hectare of soil can exceed the weight of the animals above. Whilst the larger organisms such as earthworms, ants and termites are important, it is the smaller organisms (the microbes) that do most of the work.

The roles of several groups of soil microbes is described in table 2.

TYPE OF MICROORGANISM	FUNCTION IN THE SOIL
Symbiotic N-fixing bacteria eg *Rhizobia* and *Bradyrhizobium* species	Fix atmospheric nitrogen in symbiosis with legume plants
Non-symbiotic N-fixing bacteria eg *Azospirillum*, *Azotobacter* species	Fix atmospheric nitrogen in bulk soil, near crop residues and in rhizosphere
Nitrifying bacteria eg *Nitrosomas* and *Nitrobacter* species	Convert ammonia nitrogen into plant available nitrate form
Sulphur-oxidizing microbes eg *Thiobacillus thioxidans*, most heterotrophic bacteria and fungi	Convert elemental sulphur and organic sulphur into plant-available sulfates
Vesicular Arbuscular Mycorrhiza (VAM) (except for crops such as canola)	Facilitate the uptake of phosphorus and zinc by most agricultural crops
Phosphorus-solubilising bacteria (eg *Penicillium* species)	Solubilise plant-unavailable inorganic and organic phosphorus into available forms
Denitrifying bacteria eg *Thiobacillus denitrificans*	Convert nitrate nitrogen into nitrogen and nitrous oxide gasses
Sulphur-reducing bacteria eg *Desulfovibrio* species	Reduce sulphate sulphur into hydrogen sulphide gas
Cellulolytic bacteria and fungi eg *Cellulomonas* species	Decompose cellulose and like compounds in crop residues
Plant growth promoting rhizobacteria eg *Pseudomonas* spp, *Bacillus* spp, *Streptomyces* spp	Promote above-ground and/or below-ground plant growth through hormone production or other mechanisms
Rhizoctonia solani, *Pythium ultimum*, *Fusarium* spp, *Verticillium* spp, *Ggt*)	Rhizoctonia barepatch, take-all, damping-off diseases
Bacteria: *Pseudomonas fluorescens*, *Bacillus subtilis* Fungi: *Trichoderma koningi*, *Fusarium oxysporum*, Actinomyces, *Streptomyces rimosus*	Control soil-borne plant diseases

Table 2 : Soil microbes and their roles (source V. Gupta and K. Roget)

Why soil organisms are important

Soil structure and stability

Soil organisms play an important role in forming and stabilising soil structure. Soil structure refers to the size and arrangement of aggregates and the pore space between them. A well structured soil will have sufficient porosity and stability to allow water and air to move through the soil, allow seedlings to emerge, and allow roots to penetrate and explore soil pores. It will provide resistance to erosion and have an ability to be worked by machinery. In a healthy soil ecosystem, soil particles are bound together into stable aggregates that improve water infiltration, and protect soil from erosion, crusting, and compaction.

Soil bacteria and fungi break down organic matter to make a glue substance (glomalin) that binds soil particles into aggregates, and fungi assist with aggregate formation by binding soil particles together in a net of hyphae (see figure 13). Macropores formed by earthworms and other burrowing creatures facilitate the movement of water into and through soil. Good soil structure enhances root development, which further improves the soil.

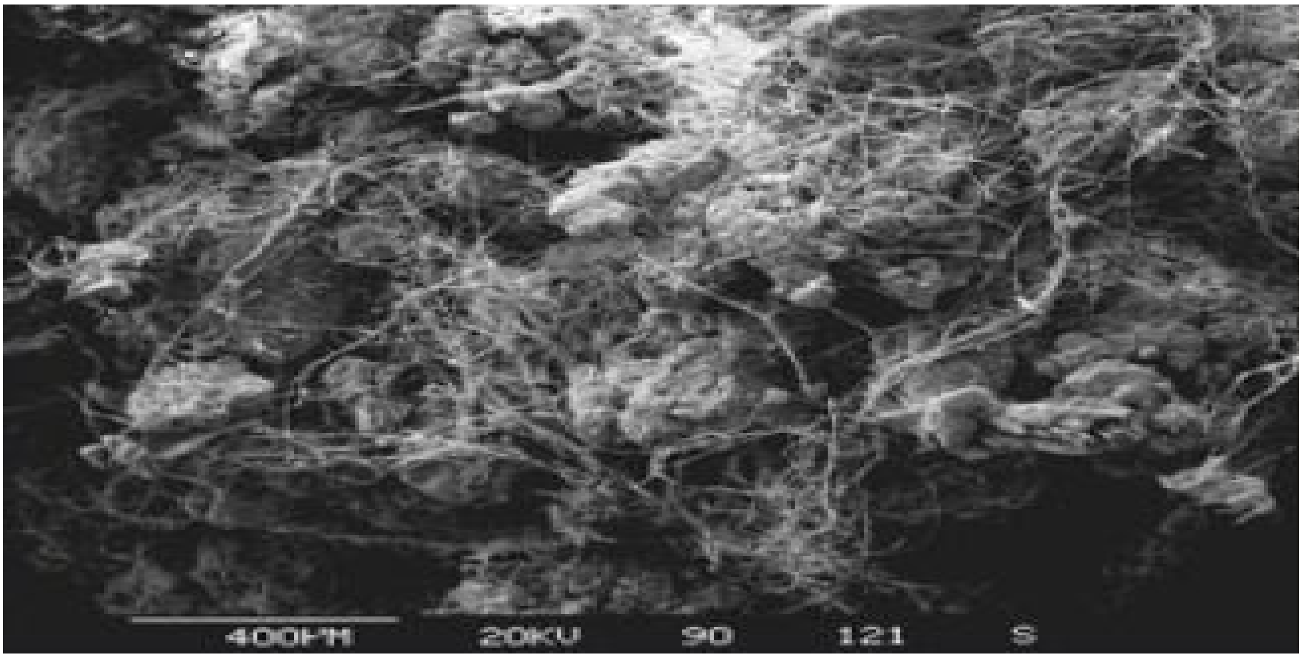

Figure 13 : A net of fungal hyphae extending through and over soil aggregates (source NSW Primary Industries)

Nutrient cycling and availability

In a healthy soil ecosystem, soil organisms regulate the flow and storage of nutrients in many ways. For example, they decompose plant and animal residues, fix atmospheric nitrogen, transform nitrogen and other nutrients into various organic and inorganic forms, release plant available forms of nutrients, mobilise phosphorus, and form mycorrhizal associations for nutrient exchange. Even applied fertilisers may pass through soil organisms before being utilised by crops.

Soil bacteria and fungi free up elements such as carbon, nitrogen, phosphorous and sulphur from decaying plant matter, dead organisms, and faeces. In addition some bacteria (rhizobia) are capable of fixing atmospheric nitrogen through the roots of legumes.

The role of mycorrhizal fungi in transferring nutrients to plant roots, in exchange for carbon has been explained in previous sections. This symbiotic relationship is extremely important in terms of freeing up organic nutrients, and for building soil carbon levels.

It is the interactions between microbes and organic matter in the soil that largely determine the fertility and overall quality of the soil. Therefore it is extremely important to use farm management practices that maintain organic matter levels, especially biologically available organic matter, in our soils.

Water quality and quantity

By improving or stabilising soil structure, soil organisms help reduce runoff and improve the infiltration and filtering capacity of soil. In a healthy soil ecosystem, soil organisms reduce the impacts of pollution by buffering, detoxifying, and decomposing potential pollutants. Bacteria and other microbes are increasingly used for remediation of contaminated water and soil.

Plant health and crop protection

Soil organisms have been shown to play an important role in improving the health of crops and pastures. An optimal diverse community of organisms in the soil can actively assist in reducing the incidence of soil-borne plant pests and diseases through the emergence of a disease suppressive state. They can also directly and indirectly improve the nutritional status of plants which can in turn lead to better plant immunity. In both cases a reduction in the need for external plant protection chemicals can occur.

Biologically fertile soils have disease suppressive functions that can control the incidence of soil borne plant pests and diseases through regulated cycles and food webs of a functioning soil ecosystem. This occurs through four key ways:

1. Habitat modification: where one organism in the soil modifies the soil habitat through its behavior (eg: it may change the soil oxygen levels) in a way that makes the soil unsuitable for another organism which happens to be a plant pathogen.
2. Predator/parasite relationships: where predator species (beneficials) eat other species (pests) and so control their population levels to a level that causes no economic damage to crops.
3. Competitive exclusion: where a non-pathogen organism outcompetes a potential pathogen for the same space (same niche) near or on the plant's roots. Thus the potential pathogen cannot successfully establish itself.
4. Antibiosis: where a non-pathogenic organism actively excludes a potential pathogen through the excretion of antibiotic substances.

Plants grown in biologically fertile soils may have a greater immunity to pests and diseases. This is due to the development of improved immune systems due to an improved nutritional profile (both quantitatively and qualitatively).

The specific roles of each group of soil micro and macro-organisms

Bacteria

These are the most numerous type of soil organism, with every gram of soil containing at least a million bacteria. There are many different species of bacteria, each with its own role in the soil environment.

One of the major benefits bacteria provide for plants is in making nutrients available to them. Some species release nitrogen, sulphur, phosphorus, and trace elements from organic matter. Others break down soil minerals, releasing potassium, phosphorus, magnesium, calcium, and iron. Other bacterial species make and release plant growth hormones, which stimulate root growth.

A few species of bacteria fix nitrogen in the roots of legumes, while others fix nitrogen independently of plant association. Bacteria are responsible for converting nitrogen from ammonium to nitrate and back again, depending on certain soil conditions.

Fungi

Fungi come in many different species, sizes, and shapes in soil. Some species appear as threadlike colonies, while others are one-celled yeasts. Slime moulds and mushrooms are also fungi.

Many fungi aid plants by breaking down organic matter or by releasing nutrients from soil minerals. Fungi are generally quick to colonize larger pieces of organic matter and begin the decomposition process. Some fungi produce plant hormones, while others produce antibiotics including penicillin. There are even species of fungi that trap harmful plant-parasitic nematodes.

Roots colonized by mycorrhizal fungi are less likely to be penetrated by root-feeding nematodes, since the pest cannot pierce the thick fungal network. Mycorrhizae also produce hormones and antibiotics that enhance root growth and provide disease suppression.

Actinomycetes

Actinomycetes are threadlike bacteria that look like fungi. While not as numerous as other soil bacteria, they too perform vital roles in the soil. Like other bacteria, they help decompose organic matter into humus, releasing nutrients. They also produce antibiotics to fight diseases of roots. Many of these same antibiotics are used to treat human diseases. Actinomycetes are responsible for the sweet, earthy smell noticed whenever a biologically active soil is tilled.

Algae

Many different species of algae live in the upper half-inch of the soil. Unlike most other soil organisms, algae produce their own food through photosynthesis. They appear as a greenish film on the soil surface following a saturating rain. Algae improve soil structure by producing slimy substances that glue soil together into water-stable aggregates. Some species of algae (the blue-greens) can fix their own nitrogen, some of which is later released to plant roots.

Protozoa

Protozoa are free-living microorganisms that crawl or swim in the water between soil particles. Many soil protozoa are predatory, eating other microbes. One of the most common is an amoeba that eats bacteria. By eating and digesting bacteria, protozoa speed up the cycling of nitrogen from the bacteria, making it more available to plants.

Nematodes

Nematodes are abundant in most soils, and only a few species are harmful to plants. The harmless species eat decaying plant litter, bacteria, fungi, algae, protozoa, and other nematodes. Like other soil predators, nematodes speed the rate of nutrient cycling.

Arthropods

There are many other species of soil organisms besides earthworms that can be seen with the naked eye, including millipedes, centipedes, slugs, snails, and springtails. These are the primary decomposers, and their role is to eat and shred the large particles of plant and animal residues. Some bury residue, bringing it into contact with other soil organisms that further decompose it.

Earthworms

Earthworm tunnels can increase water infiltration rate 4 to 10 times that of soils lacking worm tunnels This reduces water runoff, recharges groundwater, and helps store more soil water for dry spells. In addition to organic matter, worms also consume soil and soil microbes. The nutrient-rich excretion from worms is known as *worm casts,* which has a soluble nutrient content considerably higher than that of the original soil.

Did you know that one kilogram of healthy top soil can contain:

⇒ *Up to 10 billion bacteria*

⇒ *Up to 100 km fungal hyphae.*

⇒ *Up to 1 million protozoa*

⇒ *Up to 10,000 nematodes*

⇒ *Up to 5000 micro arthropods*

⇒ *Up to 10 earthworms*

Getting the balance right

Well known soil biologist Dr Elaine Ingham from the Soil Foodweb Institute states that the expected numbers of each group of organisms in a healthy soil depends on soil parent material, organic matter levels, hydrology, climate, interactions between the organism groups, and the plant that is being grown. Dr Inghams research has identified the approximate correct balances between the species groups for a "healthy soil". The numbers of each group that should be found in the top 10 cms are shown in table 3 (based on current data).

SOIL MICRORGANISM GROUP	PER 1 GRAM OF SOIL
Active bacterial biomass	50 milligrams
Total bacterial biomass	100 milligrams
Active fungal biomass	50 milligrams
Total fungal biomass	100 milligrams
Mycorrhizal colonisation	40 to 80 % depending on crop
Protozoa: flagellates	5,000 to 8,000
Protozoa: amoebae	5,000 to 10,000
Protozoa: ciliates	100 to 2,000
Bacterial-feeding nematodes	5 to 20
Fungal-feeding nematodes	2 to 10
Predatory nematodes	0 to 5
Root-feeding nematodes	0
Microarthropods	100 to 1,000

Table 3 : Microorganism population in a healthy soil (source Soil Food-web Institute)

Dr Ingham believes that a typical sandy loam agricultural soil would perform best with a 1:1 fungal to bacterial biomass ratio. The Soil Foodweb Institute recommends a full soil biology test to determine the status of the soils biological populations and ratios of species.

How management practices can impact on soil organisms

All human agricultural landuse creates disturbances to the natural system. Disturbances include fire, tillage, compaction, overgrazing, disease, and fertiliser and pesticide applications. The frequency, severity, and timing of disturbances determines their effect on soil biological activity.

Soil microbes are totally dependant on organic matter, so any practice that has an impact on reducing soil organic matter (and therefore soil carbon) will have a profound effect on the population density and species diversity of soil microbes.

Tillage

Tillage can be beneficial or harmful to a biologically active soil, depending on what type of tillage is used and when it is done. Tillage affects both erosion rates and soil organic matter decomposition rates. Tillage can reduce the organic matter level in croplands to below 1%, rendering these soils biologically dead. High organic matter levels are critical for soil biology survival.

Minimum and zero tillage practices cause much less disturbance, however the increased reliance on chemicals for weed control may counterbalance the desirable effects of reduced tillage.

Pesticides and fertilisers

Unfortunately there has only been a limited amount of research carried out on the impacts of pesticides and fertilisers on soil biology to date. However, there is enough data available to show that a number of pesticides and fertilisers can have an adverse impact on the soil microbial population and the balance between species.

All pesticides impact some non-target organisms. Heavy pesticide use tends to reduce soil biological complexity. Total microbial activity may increase temporarily as bacteria and fungi degrade a pesticide, but effects will vary with the type of pesticide and species of soil organism.

Labels generally do not list the non-target organisms affected by a product. In fact, few pesticides have been studied for their effect on a wide range of soil organisms. Pesticides that kill above ground insects can also kill beneficial soil insects. Foliar insecticides applied at recommended rates have a smaller impact on soil organisms than fumigants or fungicides. Herbicides probably affect few organisms directly, but they affect the food and habitat of soil organisms by killing vegetation.

Commercial fertilisers can be a valuable resource to farmers. Commercial fertilisers have the advantage of supplying plants with immediately available forms of nutrients. Many commercial fertilisers appear to be harmless to soil organisms, but some are not. Two examples of fertilisers that may have a harmful impact on soil organisms are anhydrous ammonia and potassium chloride.

Anhydrous ammonia contains approximately 82% nitrogen and is applied subsurface, generally as a cold-flow liquid. Anhydrous speeds the decomposition of organic matter in the soil, leaving the soil more susceptible to compaction as a result. Studies in the 1950s showed that anhydrous ammonia did alter the soil biology for a short period. The high concentration of ammonia in the retention band, which was not immediately fixed onto the soil, reduced the populations of all bacteria, fungi, nematode, and actinomycetes species.

Bacteria and actinomycetes recover within one to two weeks to levels higher than those prior to treatment. Soil fungi, however, may take seven weeks to recover.

During the recovery time, bacteria are stimulated by the high soil nitrogen content to increase in population, and decompose more organic matter. As a result their numbers increase after anhydrous applications, then decline as available soil organic matter is depleted. When bacterial populations and soil organic matter levels decrease, aggregation declines because existing glues that stick soil particles together are degraded.

Potassium chloride, also known as muriate of potash, contains approximately 50-60% potassium and 40% chloride. Muriate of potash is made by refining potassium chloride ore, which is a mixture of potassium and sodium salts and clay from the brines of dying lakes and seas. The potential harmful effects of potassium chloride on soil organisms can be surmised from the salt concentration of the material. Potassium sulfate, potassium nitrate, or organic sources of potassium may be considered as alternatives to potassium chloride for correcting potassium deficiencies.

Queensland Department of Primary Industries and Fisheries soil biologist Nikki Seymour has compiled a summary of (albeit limited) research data on the impacts of pesticides and fertilisers on soil biota. This summary is outlined in table 4.

Figure 14 : Application of anhydrous ammonia fertiliser may result in the short-term deaths of soil microbes and some decline in soil structure

CHEMICAL OR PRODUCT	ORGANISMS	EFFECT OR IMPACT ON NON-TARGET MICROBES	REFERENCE
Herbicides	Nitrifying and denitrifying bacteria	Prosulphuron inhibited N_2O and NO production by bacteria	Kinney *et al* 2005
	Mycorrhizal fungi	Decreased in some situations. Reductions due to recommended rates of 2,4-D, simazine, diuron, monuron and cotoran	Dodd and Jeffries 1989
	Protozoa	As herbicide is decomposed, increases in protozoa attributed to stimulation of bacteria and fungal populations	Gupta 1994
	Earthworms	No effect in top 10 cm	Mele and Carter 1999
	Microarthropods and microflora	Paraquat and glyphosate altered activities and reduced decomposition of crop residues	Hendrix and Parmelee 1985
	Collembola and mites	Adverse effects of atrazine and simazine for up to four weeks	Gupta 1994
Insecticides	Bacteria	Chlorpyrifos reduced numbers	Pandley and Singh 2004
	Fungi	Chlorpyrifos significantly increased numbers	Pandley and Singh 2004
	Protozoa	Diazinon decreased populations	Ingham and Coleman 1984
	Earthworms	Extremely sensitive to organophosphates and carbamates, less sensitive to organochlorines although can be affected over time due to persistence of these chemicals	Fraser 1994
Fungicides	Nitrifying and denitrifying bacteria	Mancozeb and chlorothalonil inhibited N_2O and NO production	Kinney *et al* 2005
	Earthworms	Copper oxychloride very toxic to earthworms	Lee 1985
P fertilisers	Mycorrhizal fungi	Increasing P concentration to very high levels decreases colonisation of roots and/or spore numbers in soil	Jensen and Jacobsen 1980 Seymour 2002
N fertilisers	Mycorrhizal fungi	Spore numbers and root colonisation decreased	Hayman 1970
	Protozoa	Significant increases, stabilisation and decreases have all been reported	Gupta 1994
	Actinomycetes	No effect on total count	Zaitlin *et al* 2004
	Earthworms	Increases due to long-term applications of N fertiliser to wheat and barley	Fraser 1994
	Root lesion nematodes	*Pratylenchus thornei* increased with long-term use of N fertiliser on wheat crops	Thompson 1992
Lime	Mycorrhizal fungi	Little effect on colonisation/change	Wang *et al* 1985
	Earthworms	Often increases populations – probably due to raised pH	Fraser 1994
Sulphur	Bacterial-feeding protozoa	30 – 71% decline in populations	Gupta and Germida 1988
	Fungal-feeding amoebe	More than 84% decline in populations	Gupta and Germida 1988
	Fungi	Reduced biomass	Gupta and Germida 1988

Table 4 : Examples of the impacts of pesticides and fertilisers on soil biology, as reported in scientific literature (N. Seymour, QDPI&F)

How to improve the biological activity of your soil

Soil carbon and soil biological activity are intrinsically linked. Therefore management practices that are implemented to improve soil carbon levels will improve soil biological activity, and vice versa.

The Soil Foodweb Institute suggests that landholders concerned about their soil biological status should carry out a full soil biology assessment with an accredited laboratory. Once the biological status of the soil is determined, steps to improve the population and diversity of soil microbes can be put in place.

There are however a range of management practice principles that can be adopted that will be beneficial to the soil microbiology.

Maximise groundcover at all times

The soil should be covered for as long as possible by green plants or at least stubble to protect from high temperature and water loss. A litter layer as cover will be a continuous source of carbon for soil organisms and also provide temperature insulation and water retention.

Maximise the period of active plant growth

Adoption of time controlled grazing, double or opportunity cropping, green manuring and pasture cropping are all practices that prolong plant growth, and have a beneficial effect on soil microbes.

Include a carbon source with inputs

Adding a carbon source such as fulvic or humic acid to chemical and fertiliser inputs will act as a buffer, and feed microbes. For example, BioNutrient Solutions suggests adding fulvic acid and molasses when using glyphosate to control weeds. The addition of these compounds will improve efficacy of the chemical and buffer microbes from the applied chemical. Contact BioNutrient solutions for more information.

Feed the bugs

There are a number of commercial products available that have the sole purpose of feeding specific types of microbes. However farmers are advised to ascertain their soils biological status prior to adding specific food, in order to correct or maintain balances such as bacteria to fungi.

Switch to more 'biologically friendly' fertilisers

There are an increasing number of companies promoting and supplying more naturally based fertilisers, especially for use in the growing organic and biological farming sectors. Farmers would be advised to conduct some comparative trials with a range of alternative fertilisers in small areas before making a complete switch.

Prior to using any fertiliser, farmers should ascertain their soils fertility status with a comprehensive soil test.

Feeding soil microbes

Each species of soil microorganism requires specific conditions and food types for their survival and proliferation. Dr Elaine Ingham from the Soil Foodweb Institute has conducted considerable research into the types of food microbes require, and her suggestions are summarised in the following passages.

Bacteria

Bacteria prefer foods such as simple sugars, simple proteins, and simple carbohydrates. Molasses, fruit juice, fish emulsion and green plant material high in cellular cytoplasmic material feeds bacteria. The more kinds of sugars and simple substrates added, the greater the diversity of species of bacteria, and the more likely the full range of beneficials will be present. Bacterial and fungal inoculants can be found in most good aerobic composts, or in compost teas made with compost that doesn't contain *E. coli* or other human pathogens.

Fungi

Fungi prefer complex sugars, amino sugars, complex proteins, soy bean meal, hydrolysed fish, fish oils, cellulose, lignin, cutins, humic acids, fulvic acids, wood, paper or cardboard. The more kinds of fungal foods that are present, the greater the diversity of fungal species will grow.

There are VAM spore inoculants available from a few suppliers. Yeasts are rarely useful fungal species in soil, or at least there is little data to support their usefulness.

Protozoa

Protozoa consume bacteria, and thus to improve protozoan numbers, bacterial biomass needs to be enhanced. Protozoa inoculants are compost, compost tea, and some commercially available protozoan cultures.

Nematodes

Nematodes consume bacteria, fungi and each other. Inoculants of certain entomopathogenic nematodes are available, for control of certain insect species, such as root grubs and root weevils. Compost and compost tea are the only source of inoculants for the beneficial nematodes.

Mycorrhizal fungi

Mycorrhizal fungi need plant roots to germinate and grow successfully. Humic acids can improve germination, but then the germinated fungus has to rapidly find a root to colonize or it will die. Spore inoculants are available for a range of different mycorrhizal fungi. It is important to use the kind needed for the plant, and make certain to get the spores into the root system of the plant, such as injecting the spore, or adding compost mix into the soil.

Figure 15 : 100% groundcover and growing plants, such as in this pasture cropped paddock, should lead to improved soil biological activity (photo P. Crawford)

Currently available biological inputs

Biological stimulants

The role of these products is to stimulate the microbial processes in the soil, on plant residues and on plants to enhance nutrient cycling. They include organic acids, sugars, proteins, amino acids and a wide range of other bio-compounds that stimulate microbes.

Examples include humates, fulvic acids, seaweeds and molasses.

Biological inoculants

These products add living microbes to either plants, residues or soils. They can either be specific microbes or broad spectrum products with a wide range of organisms in them.

Examples include compost teas, endophyte products, and specific inoculants (rhizobia, VAM products).

Fertilisers

Mineral fertilisers

These include rock minerals, lime and gypsum. They are low soluble inputs that are used to balance and feed the soil. They rely on soil biological function to be effective.

Mineral fertilisers contain nutrients such as calcium, silica, phosphorous and iron, as well as trace elements.

Biological fertilisers

These are biologically available products that can be used to feed plants or to balance and feed the soil. They rely on soil biological function to be most effective. The elements in these products are mostly in a biochemical form.

Examples include liquid fish extract, bio-activated minerals, powerphos.

Soluble fertilisers

Granules such as urea and liquid fertilisers provide readily available nutrients to feed plants. These fertilisers will be more effective under good levels of biological fertility but continued, high use may result in a decline in soil biological activity.

Biological pest and disease inputs

These are 'soft' non toxic inputs that can include minerals, plant or biologically derived active compounds that have minimal impacts on crop and farm ecosystem diversity.

Examples include Abrade, spinosad products, Entrust.

Combination products

These products combine two or more of the other kinds of inputs. A combination product could include bio-stimulants plus inoculants plus nutrients. They can be used as transition fertilisers when people are moving over to biological farming and have low levels of soil biological fertility.

Examples include liquid fish extract, and fortified seaweed products. These products are combined to ensure an optimal response from any inoculant that is applied.

Improving soil biology will require a holistic approach, including:

⇒ Improved management practices that focus on the retention of groundcover and green plants

⇒ Reducing reliance on synthetic fertilisers and chemicals

⇒ On-farm trials of alternative products evaluated over several seasons to assess effectiveness

Nitrous oxide – how to win from not losing it

Almost 80% of nitrous oxide (N_2O) emission in Australia is produced by the agricultural sector, and this accounts for around 3.5% of Australias total greenhouse emissions. When we consider that N_2O is 300 times more potent than carbon dioxide in terms of global warming potential, it makes N_2O emissions from agriculture a significant issue.

Nitrous oxide is produced in soils primarily by soil microbes. The two main soil biological pathways that can result in N_2O emissions are nitrification and denitrification.

Nitrous oxide production from soils will vary depending upon on a number of factors including soil water content, availability of ammonium and nitrate, temperature, organic carbon levels, and soil pH. These will in turn be influenced by farm management practices such as nitrogen fertiliser management, crop rotations, soil tillage practices, and animal effluent management.

In Australia almost 90% of the increase in N_2O emissions (from 1990 to 1999) has been attributed to an increase in nitrogen fertiliser use. Between 1987 and 2000, nitrogen fertiliser used on cereal crops in Australia increased by 335%. This has resulted in a 29% increase in N_2O emissions for the same period.

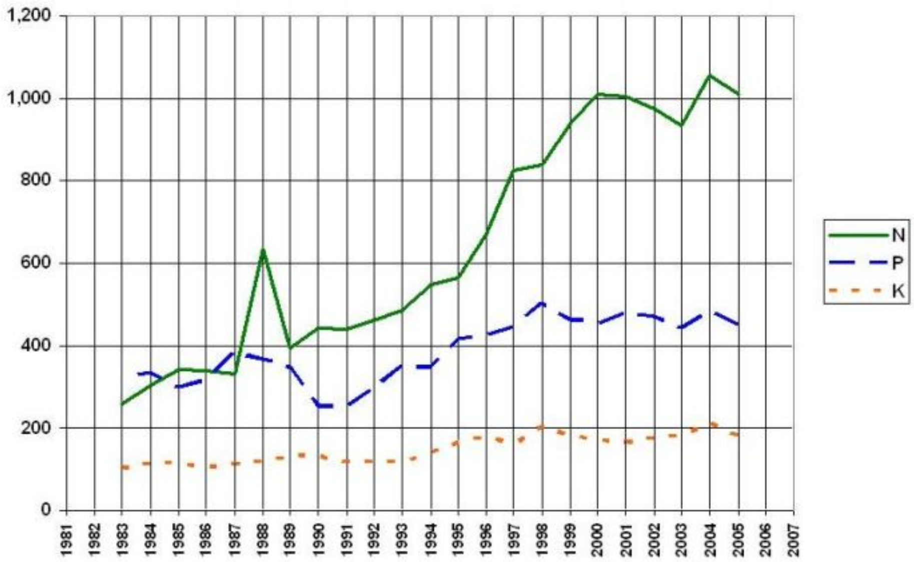

Figure 16 : Graph showing the increase in nitrogen fertiliser use, compared to other fertilisers, since the mid 1980's. Amounts are in 000 tonnes (source Fertiliser Industry Federation Australia)

The nitrogen cycle

In soils there is a store of organically bound nitrogen, which can total several thousand kilograms per hectare in many instances. Organically bound nitrogen is converted to mineral nitrogen by soil bacteria, firstly to ammonia (NH_3), and then to ammonium (NH_4). The ammonium form of nitrogen is very stable in the soil as it is tightly held on to soil particles due to a strong positive charge. This process is called mineralisation, and is the first step in making organically held nitrogen available to the plant.

Although the ammonium form of nitrogen is plant available to a certain extent, it is the nitrate form (NO_3) that is most readily plant available. The process of converting ammonium to nitrate is called nitrification.

In situations of very heavy rainfall, poorly structured or poorly drained soil, or over-fertilisation, nitrogen can be lost to the atmosphere as nitrous oxide. This occurs during a process where nitrates are broken down into more volatile gaseous nitrogen forms. This process is called denitrification.

Legumes have the capability of fixing atmospheric nitrogen into organic nitrogen in the soil. This is facilitated by the presence of nitrogen fixing bacteria (rhizobia) that form nodules on the legume plant roots. This process is known as nitrogen fixation.

Mineral nitrogen is absorbed by soil microbes, and is 'tied up' in the microbial pool of nitrogen. This process is called immobilisation.

All of the above processes make up the soil nitrogen cycle.

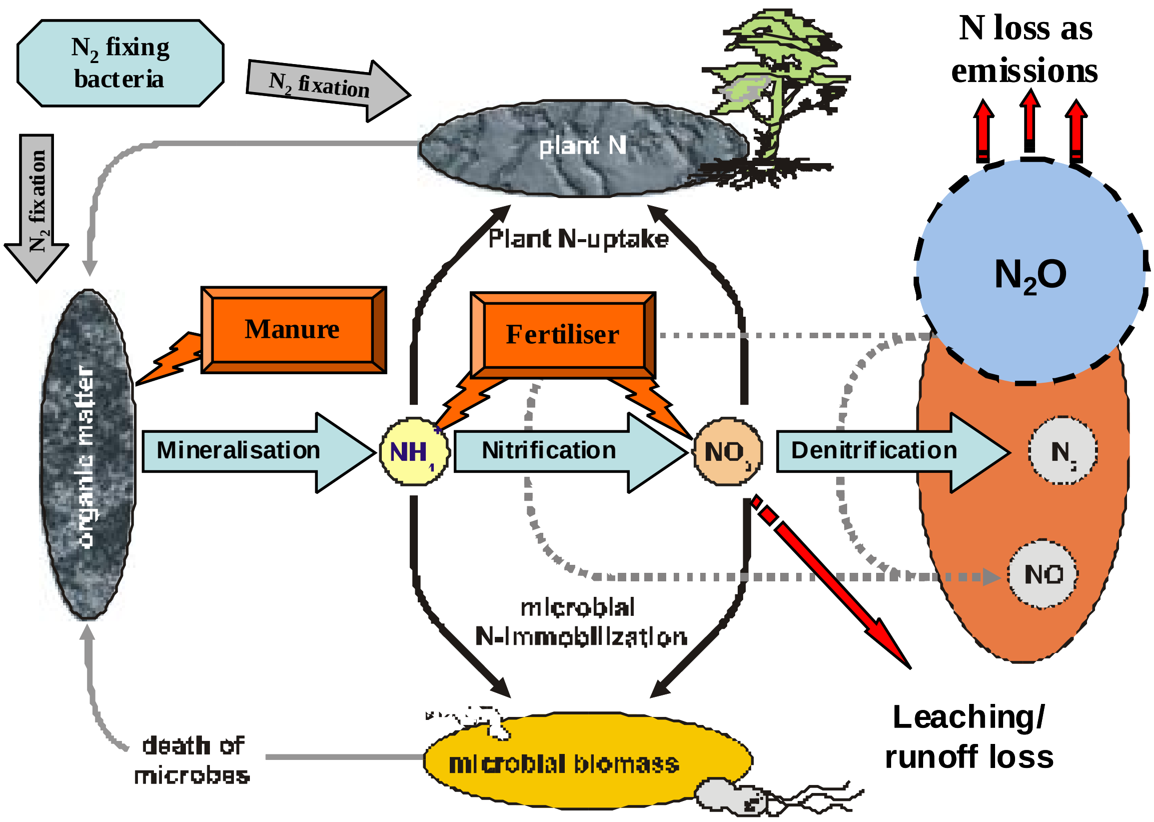

Figure 17 : The nitrogen cycle (source D. Rowlings, QUT)

Nitrification

Nitrification is the process whereby the stable ammonium is converted by soil nitrifying bacteria to the unstable but more plant available nitrate. Because of the mobility of nitrate (compared to the tightly held ammonium) it is more susceptible to losses from the soil due to leaching.

When a fertiliser such as urea is added to the soil, it undergoes the nitrification process within a period of a few days to a couple of weeks, depending on weather conditions.

Nitrification requires a good supply of oxygen for it to occur, so a well structured and well drained soil is needed for this process. Nitrification is a fundamental and necessary process for the release of organically held nitrogen for plant growth, and a well structured and well drained soil is also the ideal soil for plant growth and carbon building. Although some losses of nitrogen as N_2O can occur during the nitrification process, emissions should be minimal in a well balanced soil that is not over fertilised.

***Nitrification** – the conversion of ammonium to nitrite and nitrate caused by nitrifying bacteria. This process occurs under aerobic conditions and incomplete conversion can result in the formation of N_2O. This process relies on a good supply of oxygen hence only takes place in well drained and structured soils.*

Denitrification

Denitrification is a process whereby nitrates are converted into more volatile forms of nitrogen (such as N_2 and N_2O) by soil denitrifying bacteria. This process generally occurs after heavy rainfall when the soil is saturated or waterlogged. Denitrification is the process causing most nitrogen losses and N_2O emissions from the soil, and it is highly event based.

Denitrification can be exacerbated by:

⇒ Poor soil management, resulting in poor structure, lack of drainage and poor biological activity

⇒ Low soil carbon to nitrogen ratio

⇒ Inappropriate or untimely applications of nitrogen fertiliser

⇒ Heavy rainfall during a fallow period where there are no growing plants

⇒ Soil temperature and anaerobic conditions

***Denitrification** – the conversion of nitrate and nitrite to nitrogen gas forms, caused by denitrifying bacteria. During this process N_2O is produced, with some of the N_2O escaping to the atmosphere prior to conversion to nitrogen (N_2) gas. Denitrification occurs in wet and waterlogged, or anaerobic, soils.*

Improving nitrogen fertiliser management

Research has shown that 1.25% of all nitrogen fertiliser is emitted as N_2O from cropped soils. However, total nitrogen losses can be much higher with over 20% of nitrogen fertiliser lost as nitrogen gas (N_2) in some situations. This represents a significant economic loss in times of high fertiliser prices, as well as a significant addition to Australias greenhouse gas inventory. The potential for loss will vary according to whether the crop is irrigated or dryland, the soil type, and whether there are extremely wet weather conditions.

Most nitrogen fertiliser losses from soils can be directly attributed to one or more of the following reasons:

⇒ Overfertilisation – application of large amounts of nitrogen fertiliser beyond the needs of the crop

⇒ Timing of application – such as pre-planting nitrogen fertiliser several months prior to planting

⇒ Adherence to a standard application rate each year without a soil test or nitrogen budget

⇒ Drought conditions leading to a crop failure, followed by a period of heavy rainfall

The impacts of over-application of N

Research carried out in the Darling Downs region from 1993 to 1995 revealed a considerable amount of nitrate nitrogen at depth (below 60 cm) in cropping soils. Scientists refer to this as a ‘bulge’. This has occurred because excess nitrate nitrogen (N not used by the crop) has moved down through the soil with water entering the profile. This nitrogen may be unavailable to subsequent crops due to it being too deep to be accessed by plant roots, so in effect it could be wasted. In most cases this excess nitrate nitrogen would have been caused by excess rates of nitrogen fertiliser being applied.

Deep coring to a depth of 1.8 metres revealed very high levels of nitrate nitrogen, from 50 to 150 kgs per hectare, in the 60 to 90 cm layer. All of this nitrogen is not necessarily lost to the system, with some becoming available when plants extend roots to deeper levels in search of moisture, but at an average of 100 kgs per hectare stored at this depth, current nitrogen prices would show this to be a potential loss of up to $170 per hectare.

Research carried out by NSW DPI following the 1994 drought revealed high nitrate nitrogen levels at all depths of the soils sampled at a range of sites. The key points from this research were:

⇒ Soil nitrate levels increase following a drought

⇒ Enough rain falls during a drought for mineralisation to occur

⇒ Soil nitrate levels need to be balanced with target yield and protein

⇒ Soil sampling is the most reliable method for determining soil nitrate levels

Nitrogen budgeting

Estimating the amount of soil nitrate the paddock can supply for a crop can be done through a combination of soil sampling and the use of historical data on yields and protein content.

To determine a nitrogen fertiliser rate, nitrogen supply needs to be balanced with the nitrogen demand of the next crop. To achieve this a nitrogen budget should be prepared prior to planting each crop, with soil sampling carried out each season. The nitrogen budget will take into account plant available water, estimated yield, and nitrogen supply in the soil. A nitrogen budget calculator and example is shown in table 5.

When preparing a nitrogen budget, the following points should be considered:

⇒ Soil tests need to be taken as close as possible to planting time to take into account N mineralisation before planting

⇒ There will be a small amount of N mineralisation during the growing period of the crop

⇒ Deep core sampling should be carried out at regular periods to ascertain if there is a nitrogen bulge

CALCULATION	EXAMPLE
Calculate total available water (mm) = fallow water storage + estimated in-crop rainfall *	Plant available water 100 mm
Calculate yield target (t/ha) = based on history and total available water	2.5 t/ha
Calculate protein target (%) = based on crop type and variety, history	12%
Calculate grain nitrogen demand (kgs N/ha) = yield target (t/ha) x protein target (%) x 1.75 (protein conversion factor)	2.5 x 12 x 1.75 = 52.5 kgs/ha
Crop N requirement = grain N demand x 2 (N transfer efficiency is 50%) **	52.5 x 2 = 105 kgs/ha
Estimated soil N available (from soil test)	34 kgs/ha
Typical in-crop mineralisation of N ***	30 kgs/ha
Gross N supply = soil test N + estimated in-crop mineralisation	34 + 30 = 64 kgs/ha
Extra N required = crop N requirement - gross N supply	105 - 64 = 41 kgs/ha N required
Calculate fertiliser rate (kgs/ha) = fertiliser N required x 100 ÷ analysis %	Urea 46% N: 41 x 100 ÷ 46 = 89 kgs urea required DAP 18% N: 41 x 100 ÷ 18 = 227 kgs DAP required

Table 5 : Nitrogen budget calculator for wheat (source Soil Matters)

Notes to the nitrogen budget table

* Fallow water storage can be measured with a soil probe. Plant available water (PAW) in millimetres is calculated by multiplying the depth of wet soil (cms) by a factor of 1.2 (light sandy soils) to 1.9 (heavy clay soils). For example, probe depth in a medium clay soil is 70 cms, PAW = 70 x 1.6 = 112 mm.

** The 50% efficiency of N recovery by plants is based on many studies which show that the crop on average takes up about half of the available N. This does not mean that the other 50% is lost, with up to 30% being taken up by the roots and available for future crops.

*** N mineralisation during the growing season can vary from 15 kg/ha to 100 kg/ha depending on the soil type and age of cultivation

The Qld. DPI&F have developed a nitrogen fertiliser calculator in electronic form. It is included on a CD titled *The nitrogen book*, available from QDPI&F free of charge. Phone 132523 for a free copy.

Reducing losses by delaying or splitting nitrogen fertiliser applications

Nitrogen fertiliser is traditionally applied late in the fallow prior to planting a crop, generally for management reasons rather than agronomic reasons. Sometimes this can occur many weeks prior to planting, especially if planting is delayed due to lack of rainfall. Urea is the most common form of nitrogen fertiliser used, and if applied early urea is very vulnerable to losses, through leaching and denitrification.

Delaying nitrogen application can be viewed as a risk management strategy. In cases of marginal soil moisture it may be a good strategy to split the nitrogen into two or more applications, the amounts applied based on the original soil test and any changed seasonal conditions. For example, good rainfall a few weeks into the growing period may lead to an increased yield potential, so additional nitrogen may be needed to take advantage of this. This is becoming a very common practice in the US and Canada, and with rising fertiliser prices this practice is likely to gain more popularity in Australia.

The graph shown in figure 18 demonstrates the uptake of nitrogen in relation to the growth stage of wheat plants. By timing nitrogen application to suit the peak uptake period (mid tillering to boot stage) nitrogen losses could be significantly reduced.

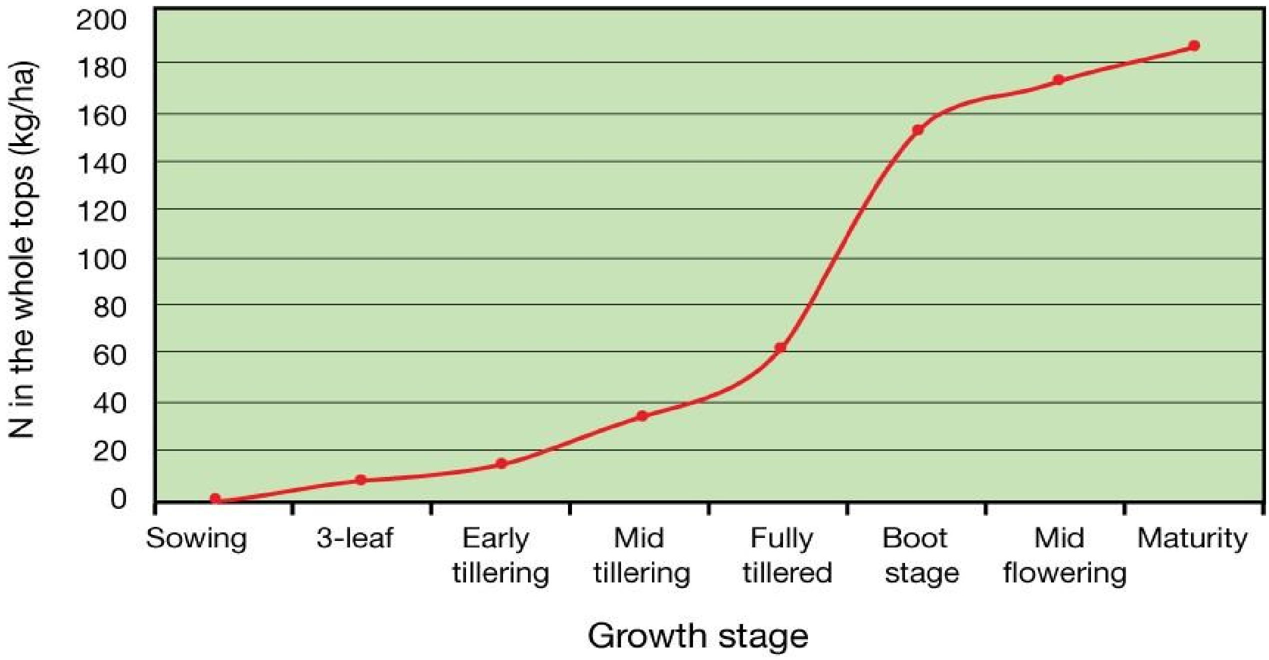

Figure 18 : The relationship between growth stage and nitrogen uptake in high yielding wheat crops (source Incitec Pivot Limited 2009)

Nitrogen loss inhibitors

Urea is the most common form of nitrogen fertiliser used throughout the world. Urea has the highest analysis of N by weight, it is relatively inexpensive to manufacture, it is freely available, and it is easy to apply. Within 3 to 10 days of application urea is converted to ammonia (NH_3) by the enzyme urease, and then to ammonium (NH_4). The process of nitrification by nitrosomas bacteria converts the ammonium to nitrite (NO_2), and then by nitrobacter to nitrate (NO_3). These processes are ammonification and nitrification.

Figure 19 : Ammonification and nitrification processes

Losses of N can occur during both of these processes, and major losses can occur once the ammonium has been converted to nitrate, through denitrification. There has been a large amount of research carried out to determine whether these processes can be slowed, through the addition of a range of additives or coatings, to better match nitrogen supply to plant demand.

There are three broad types of nitrogen loss inhibitors on the market.

1. Urease inhibitors: reduce ammonia volatilisation potential by reducing the peak pH and ammonium levels in the soil, and by allowing more time for rainfall to leach surface applied urea into the soil. Product example is Agrotain®.

2. Nitrification inhibitors: slow the nitrification process by interfering with the activity of the nitrosomas bacteria. Product example is Entec®.

3. Coating products that physically slow down the dissolution of the urea granule, delaying and/or extending the ammonification process. Products used for coating of urea include polymer, sulphur, zeolite, and oils. Commercially available coated products include Black Urea® and Green Urea®.

A research project was carried out by the University of Melbourne for the Grains Research and Development Corporation to demonstrate the potential of a range of inhibitive products to slow the rate at which ammonium is released from urea granules . The humic acid and sulphur coatings of urea granules demonstrated slowed ammonium release by 14% and 25% respectively. However, the largest effects were due to the urease inhibitor (Agrotain®) of 80% and the polymer coating 90%.

The results of this research is demonstrated graphically in figure 20.

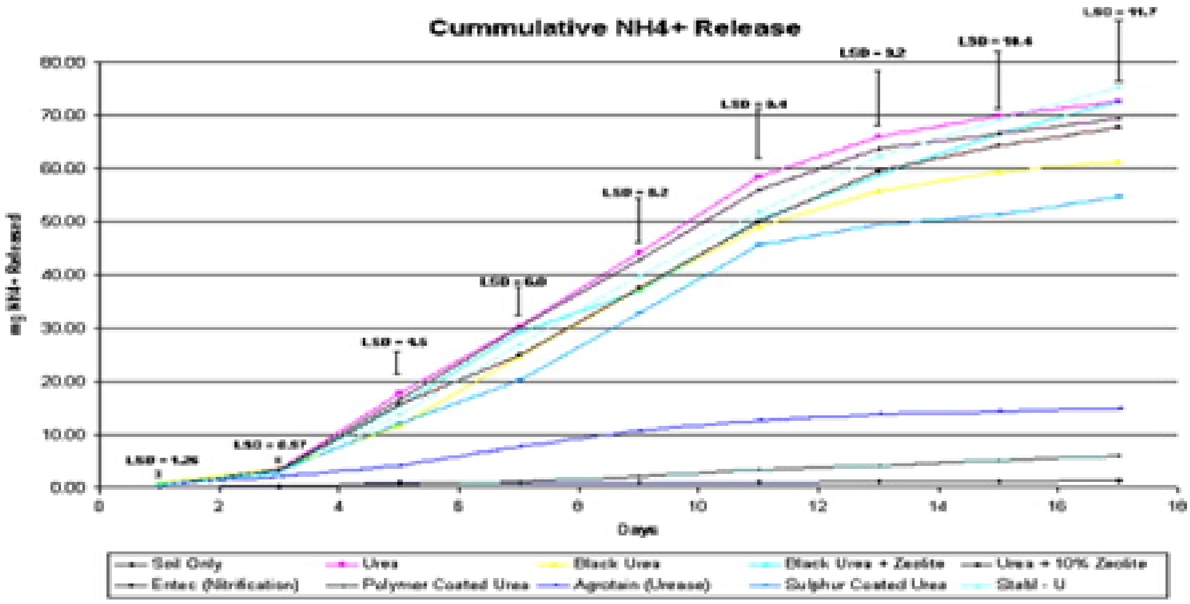

Figure 20 : Cumulative release rates of ammonium from various urea supplemented fertilisers over 17 days (source University of Melbourne)

Incitec Pivot Marketing Agronomist David Hall has been conducting trials in the Darling Downs region to measure the effectiveness of Entec® in slowing ammonium release from Big N fertiliser (anhydrous ammonia). The trials have been evaluated in terms of nitrous oxide emissions, and the early results of these trials are showing significant reductions in N losses (and therefore emissions) by using this product.

Improving nitrogen fertiliser use efficiency — a few basic facts

Fact 1: Oil prices will continue to rise, and so will the cost of N fertiliser, so minimising N losses will only become more important

Fact 2: It is not difficult to reduce nitrogen losses, by following a few basic processes, such as always taking a soil test prior to planting a crop, nitrogen budgeting, and appropriate application techniques

Fact 3: It is very likely that improved or more efficient nitrogen fertilisers will become more commonplace in the near future. Farmers would be advised to contact their fertiliser representatives for advice prior to applying any nitrogen products, in order to maximise their returns and minimise their losses

N_2O emissions from livestock

Nitrous oxide emissions in grazing systems are caused by the concentration of nitrogen in urine and dung in patches, compaction of the soil due to trampling, and from nitrogen fixed by legumes or applied as fertiliser. The Australian National Greenhouse Gas Inventory Committee estimates that grazed pastures contribute more than 43% of Australias N_2O emissions.

It should be noted that this estimate is based on enclosure experiments, so further work needs to be carried out to accurately extrapolate this data to field conditions. However, overseas research suggests that intensive grazing situations such as dairy farms are significant contributors to N_2O emissions.

Nitrate availability

Pasture plants require significantly more nitrogen for growth than animals need for protein synthesis. Therefore grazing animals utilise very little of the nitrogen present in feed, and so can excrete 75 – 90% of the nitrogen taken in through ingestion of high nitrogen feed. In intensive animal systems (such as dairying and feedlots) the excreted nitrogen is often applied to grazing land as effluent or manure, whilst in less intensive systems the nitrogen is excreted directly as urine or dung.

The main nitrogen component of urine is urea, whilst the dung nitrogen component is organic nitrogen which is more stable than urea nitrogen. As a result animal urine patches are the dominant source of nitrogen that is emitted as N_2O in a grazing system due to the highly localised concentrations of readily available nitrogen in each patch.

Effluent management

It is estimated that globally 30% of nitrogen excreted by livestock is deposited in livestock housing systems and subsequently treated or applied to pastures as effluent. Research in New Zealand suggests that N_2O emissions from effluent are higher when applied to wet soil compared to application to drier soil, and that emission peaks generally occurred within 24 hours of application. Therefore the timing of application of effluent in relation to soil moisture may be an effective emission reduction strategy.

The timing of nitrogen fertiliser application in relation to effluent application can affect N_2O emissions, with emissions being lower when nitrogen fertiliser is applied at least three days after the effluent, rather than at the same time.

Incorporation of effluent into the soil may decrease total N_2O emissions, and is likely to increase the overall nitrogen use efficiency of the effluent, which may reduce the amount of nitrogen fertiliser needed.

Fertiliser management

The principles relating to the management of nitrogen fertiliser application to grazed pastures are the same as for a cropping situation: that is, nitrogen application rates and timing should be closely aligned with the anticipated pasture response. The anticipated pasture response to applied nitrogen can be calculated from available information including plant growth stage, soil moisture, and available soil nitrogen.

Dietary supplements

Recent research has shown that supplementation of salt to dairy cows on pasture reduced the nitrogen concentration in their urine due to an increased water intake. Animals given salt supplements urinate more frequently, resulting in a more even distribution of nitrogen across paddocks. This should help to reduce N_2O emissions.

Balancing the protein to energy ratio in the diet of ruminants

Animals require varying protein to energy ratios in their diet according to their specific needs. For example a maintenance-only diet requires about 7% crude protein, whilst a lactating animal will require 15 – 20% crude protein. If crude protein in excess of the animals need is supplied in the diet, higher levels of nitrogen will be excreted in the urine.

Research in the United States showed that dairy cows on a 14% crude protein diet excreted 29% less nitrogen than cows on a 19% crude protein diet. The amount of nitrogen in the urine was reduced by 45%, whilst the amount of nitrogen in the dung (organic) increased by 4%. This research demonstrates that careful manipulation of the protein to energy ratio in the diet can have a significant effect on N_2O emissions, and possibly save money at the same time.

Some facts regarding N_2O emissions from livestock

⇒ *About 25% of N_2O emissions from agricultural soils can be attributed to animal production*

⇒ *A dairy cow deposits 6,000 litres of urine each year*

⇒ *This equates to about 125 kg of nitrogen that is excreted per cow per year*

⇒ *Significant reductions in nitrogen losses through urine can be achieved by manipulating the diet of livestock*

Summary and main points

Building soil carbon

⇒ Soil is the largest source of carbon on planet earth, with the worlds soils holding around three times as much carbon as the atmosphere, and over four times as much carbon as the worlds vegetation

⇒ Breakdown of organic matter in the soil does lead to some long-term carbon storage, but this process is very slow and can be disrupted through farming activities and drought

⇒ Photosynthesis is the key process for getting carbon into the soil, in association with mycorrhizal fungi

⇒ Mycorrhizal fungi are responsible for the transfer of nutrients (in particular nitrogen, phosphorous and zinc) into plant roots in exchange for soluble carbon extracted from the plant sugars. It is through this process that carbon is stored in a long-term form in humus

⇒ The survival of mycorrhizal fungi is dependant on the presence of living plants so the fungi can attach to plant roots, in a symbiotic relationship. During fallow periods in cropping systems the lack of living plant roots results in the dying out of mycorrhizal fungi, which has been identified as the major cause of poor growth rates and yield of the subsequent crop

⇒ Management practices can be either totally productive or totally destructive in terms of soil carbon

⇒ The key management practice for improving soil carbon is maximising groundcover – aim for 100% wherever possible

⇒ Soil carbon is destroyed by cultivation

⇒ Even under the best managed zero tillage system with retained stubble and a good fertiliser regime, it is not easy to build soil carbon levels, although a well managed zero tillage system should at least prevent a further decline in soil carbon

⇒ Current best practice zero tillage involves minimal soil disturbance (especially with disc openers) leaving the stubble standing, which is advocated as the best method for reducing soil erosion potential. However standing crop stubble is kept away from soil microorganisms and being exposed to the air results in the oxidisation of much of the carbon contained by it

⇒ Zero tillage farming results in a total absence of growing plants during the fallow period, resulting in a decline in the mycorrhiza population

⇒ To get the best carbon potential from a zero tillage farming system, farmers should consider:

- Putting standing stubble on the ground, using an implement such as a prickle chain or slasher
- Rotate crops, and include grain legumes in the rotation
- Introducing livestock and rotate cropping with a pasture phase where it is practical

⇒ In a well managed grazing system it is possible to build soil carbon. This system would aim for a limited reduction in plant biomass during grazing, and the retention of a high level of groundcover

⇒ The practice of pasture cropping has a huge potential for building soil carbon because of the increased periods of photosynthesis and soil biological activity

Improving soil biology

⇒ Plants depend on beneficial soil organisms to protect them from pathogens, to help them obtain nutrients from the soil, and to break down toxic compounds that could inhibit growth. Soil organisms create a living, dynamic system that needs to be understood and managed properly for best plant growth

⇒ It is often quoted that the weight of soil organisms under a hectare of soil can exceed the weight of the animals above

⇒ Soil organisms play an important role in forming and stabilising soil structure, decomposing plant and animal residues, fixing atmospheric nitrogen, transforming nitrogen and other nutrients into various organic and inorganic forms, releasing plant available forms of nutrients, mobilising phosphorus, forming mycorrhizal associations for nutrient exchange, helping to reduce runoff and improving the infiltration and filtering capacity of soil

⇒ Soil microbes are totally dependant on organic matter, so any practice that has an impact on reducing soil organic matter (and therefore soil carbon) will have a profound effect on the population density and species diversity of soil microbes

⇒ All pesticides impact some non-target organisms. Heavy pesticide use tends to reduce soil biological complexity. Total microbial activity may increase temporarily as bacteria and fungi degrade a pesticide

⇒ Some commercial fertilisers can have an adverse impact on soil microorganisms

⇒ To improve soil biological activity, farmers should:

- Maximise groundcover at all times
- Maximise the period of active plant growth
- Consider including a carbon source with inputs
- Consider switching to more biologically friendly fertilisers
- Feed the microbes

Reducing nitrous oxide emissions

⇒ Nitrous oxide (N_2O) is 300 times more potent than carbon dioxide in terms of global warming potential, and N_2O losses from agricultural soils represents around 3.5% of Australias greenhouse emissions

⇒ In Australia almost 90% of the increase in N_2O emissions (from 1990 to 1999) has been attributed to an increase in nitrogen fertiliser use

⇒ Between 1987 and 2000, nitrogen fertiliser use on cereal crops in Australia increased by 335%. This has resulted in a 29% increase in N_2O emissions for the same period

⇒ Most nitrogen losses from soils is caused by denitrification. Denitrification is a process whereby nitrates are converted into more volatile forms of nitrogen (such as N_2 and N_2O) by soil denitrifying bacteria. This process generally occurs after heavy rainfall, in saturated or waterlogged soils

⇒ Nitrous oxide emissions in grazing systems are caused by the concentration of nitrogen in urine and dung in patches, compaction of the soil due to trampling, and from nitrogen fixed by legumes or applied as fertiliser. The Australian National Greenhouse Gas Inventory Committee estimates that grazed pastures contribute more than 43% of Australias N_2O emissions

⇒ It is estimated that globally 30% of nitrogen excreted by livestock is deposited in livestock housing systems and subsequently applied to pastures as effluent or manure

⇒ Animals require varying protein to energy ratios in their diet according to their specific needs. If crude protein in excess of the animals need is supplied in the diet, higher levels of nitrogen will be excreted in the urine

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