# Carbon Grazing

## The Missing Link

**Improving plant & landscape resilience**

**Re-carbonise the soil for profit**

**De-carbonise the atmosphere**

**Reduce methane emissions**

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# CHAPTER 14
# THE CARBON:NITROGEN RATIO

## NITROGEN IS ALWAYS MOVING, LIKE CARBON

The carbon:nitrogen ratio (C:N) of living things and their residues is essential for determining the outcomes of many processes. It is always discussed in papers looking at landscape function and animal performance, yet it is rarely discussed in literature available to rural producers. Credit where it is due, it does appear in magazines like the “Australian Farm Journal” and “Farming Ahead”. Before looking at how to interpret the ratio, it is important to understand the role of nitrogen and how it cycles.

Carbon compounds provide energy and cellular building blocks, while nitrogen is a crucial component of proteins, necessary for cell growth and function. It is nitrogen that builds tissue. Nitrogen is a component of amino acids which are the building blocks of protein. Animal muscle contains protein and water. It is the individual requirement for nitrogen, by a living thing, which determines the amount of nitrogen that must be sourced. This applies to plants as well as the different types of microbes, insects and animals. Nitrogen is the primary nutrient limiting terrestrial plant production.

It has already been discussed how carbon is always moving as part of the carbon cycle, but nitrogen is not stationary either. The circulation of nitrogen through life forms and the atmosphere is known as the nitrogen cycle. Nearly all of the nitrogen present in the soil originates from the earth’s atmosphere where it makes up just under 80% of the air. Each hectare of the earth is covered by about 84,000 tonnes of nitrogen in the atmosphere.

Lightning accounts for some naturally occurring reactive nitrogen — worldwide each year, lightning fixes an estimated 3–10Tg (teragram). A teragram, which equals 1 000 000 tonnes, is the usual measurement unit for discussing the global nitrogen cycle. The energy that lightning generates converts oxygen and nitrogen to nitric oxide (NO), which oxidises to nitrogen dioxide ($NO_2$), then to nitric acid ($HNO_3$). Within days the $HNO_3$ is carried to the ground in rain, snow, hail, or other atmospheric deposition. This source of reactive nitrogen is important to areas in which nitrogen-fixing plants are scarce. Most naturally occurring reactive nitrogen comes from nitrogen fixation by bacteria.

The source of energy is photosynthesis, while the availability of nitrogen is determined by processes that occur in the soil. Putting aside man-made fertilisers and rain, the only way to get nitrogen down from the atmosphere and into the soil, in a form plants can use, is via organisms in the soil. The two ways are through the medium of the bacteria in the root nodules on “healthy” legume plants, and through the free living organisms in the soil. These free living organisms are able to “fix” atmospheric nitrogen and make it available for plant uptake. The cycle begins when soil microbes remove nitrogen from the atmosphere and use it to make nitrates and other nitrogen compounds. These microbes will not be sufficiently present in the soil if there is not a supply of organic carbon (ie they need energy and the building blocks of life if they are to exist). It is good soil structure that enhances the entry of air/nitrogen and nitrogen-carrying rain. People often comment that the garden always responds better to rain than watering with the hose. This is because of the nitrogen that arrives with rain.

*"Plants and algae absorb the nitrogen compounds in the soil. When animals and birds eat these plants, the nitrogen is absorbed and assimilated into their tissues. When all living organisms die, microbes break down their tissues into ammonia (this is called ammonification). Ammonia either evaporates into the air or is used again by microbes to create nitrates. The nitrogen cycle then begins again when plants utilise the nitrogen that soil microbes recycle from the atmosphere and organic matter."*
(Minerals Information Institute)

Just as the interchange of the use of the terms "organic matter" and "organic carbon" causes confusion for readers, the interchange of "nitrogen" and "protein" in literature also causes confusion for some. To calculate crude protein levels when nitrogen is quoted, multiply the nitrogen percentage by 6.25. For example if grass is quoted as having 2% nitrogen, then it has a crude protein level of 12.5%.

In plants, nitrogen is necessary for chlorophyll synthesis, and as part of the chlorophyll molecule, is involved in photosynthesis. It is chlorophyll that gives the plant its green colour. Lack of nitrogen and chlorophyll means that the plant will not utilise sunlight as an energy source to carry out its essential functions such as nutrient uptake. A badly managed pasture with low soil carbon levels, and hence lower nitrogen levels, struggles with carbon introduction following rain, due to a lack of nitrogen.

Very little plant-available nitrogen is present in the soil in its natural state, remembering that it has to be in a mineral form to be plant available. Most nitrogen is contained in the soil organic matter. The amount depends on the organic matter concentration and the quality of this organic matter. Nitrogen in the organic form may represent about 95%-99% of the total nitrogen in the soil. The balance is in the inorganic or mineral form, which plants are able to use. Another organic store of nitrogen is humus which is a more stable form where leaching is less likely.

As part of the bigger picture, the nitrogen/protein cycle follows carbon and is a reflection of soil fertility. Dysfunctional, ie degrading, landscapes become increasingly infertile with time, because they have **a low potential for capturing new resources**.

When any living thing dies or is consumed, it becomes the food source for another living thing. This is the story of ongoing life and promotes the recycling of nutrients, energy, and minerals. All the nutrients and trace elements are important for the next consumer, but nitrogen is a key player. It has to be passed (along with carbon) in adequate quantities down the food chain to ensure ongoing life. Pushing up daisies is us contributing to another life.

## THE CARBON:NITROGEN RATIO

Now is the time to understand what the carbon:nitrogen ratio is and how it is calculated. For the example we will look at a sample of plant residue. Suppose it is made up of 40% carbon and 2% nitrogen. Dividing 40 by 2, the result is 20. The C:N ratio of this material is 20 to 1, which means 20 times as much carbon as nitrogen.

Suppose another sample has 35% carbon and 5% nitrogen. The C:N ratio of this material would be 7 to 1. Some literature refers to the ratio as being seven and makes no reference to the one. Often in literature the C:N ratio is referred to as high or low, without reference to the actual ratio.

A high C:N ratio means the material is low in nitrogen. Put another way, the lower the C:N ratio, the higher the nitrogen content. It would have been better if they had the ratio the other way around, given that our interest is in the variation of nitrogen. **The best way to understand the concept is: the lower the figure the better**. Lucerne hay which is high in nitrogen, has a C:N ratio of about 13:1, while wheat stubble which is low in nitrogen, has a C:N ratio of about 120:1.

The first thing to understand about plants is that the carbon is fairly constant in the break-up; it is the nitrogen that varies. Most trees are about 50% carbon while grasses are about 45% carbon. Like all figures used in plant analysis, this is based on dry weight.

Humans are 18% carbon and 2.5% nitrogen, so we have a C:N ratio of 7.2. Blood has a C:N ratio of 3, which is what you would expect, given that it carries the proteins responsible for building body cells and maintaining their function. I remember as a child being told that the Chinese market gardeners kept their urine. Now I understand why, as urine has a C:N ratio of about 0.8 (ie very high in nitrogen). It also explains why urine is a fertiliser just like manure is. It is a by-product of consumption in the same way as carbon dioxide is.

The atmosphere is 0.03% carbon dioxide but it is 78% nitrogen. However, this is reversed when we look at all the living things on earth where carbon is the main component.

As part of the discussion which follows, we will look at how different plant groups have different nitrogen levels. However, we first need to appreciate that the nitrogen levels vary within each plant. This is why animals (especially sheep) will select certain plant parts over others. For a better understanding of this, I quote from "Plants in Action" (Atwell, *et al* 2001).

> *"Dry matter of a typical green plant contains a large and relatively constant proportion of carbon (35-50%). Comparable values for nitrogen in dry matter tend to be more variable, with lowest levels in roots and stems (0.5-1.5%) and considerably higher levels in leaves (3-5%) where much nitrogen is associated with enzymes involved in photosynthesis. Higher levels are encountered in seeds (6-7%) and other storage organs in which large quantities of protein are being stored."*

To this point, we have discussed how animals function, looked at the different plant groups, and considered all the processes that occur in the soil. Now is the time to discuss the effect of the C:N ratio on these processes (ie the influence of nitrogen).

As the plants are the start of the two food chains, above and below ground, the C:N ratio of the plants will determine how efficient these other consumption processes are. As the discussion proceeds, it will become obvious that the C:N of plants will be determined by what is available to them in the soil. Already the discussion is starting to become circular, so we have to pinpoint exactly what enables nitrogen to be introduced into the landscape faster than it is escaping back to the atmosphere. In the case of carbon, we discovered that the level of photosynthesis was the major determinant of the net carbon stores in the landscape, followed by the rate of decomposition due to soil disturbance, temperature, moisture etc. In the case of nitrogen, it is the level of activity in the soil, which in turn is determined by carbon introduction over time. Like carbon, there will be short-term variations in the stocks of nitrogen due to climate.

Remember that plants are consumed in 3 ways: animals (including birds), insects, soil fauna and fire, so now is the time to look more closely at the soil path. For this discussion I am indebted to an article by Van Bushby, which he has generously allowed me to reprint in part. This article crystallises the process in an uncomplicated way. Van's explanation shows why it is the quality of organic matter that determines how quickly nitrogen is recycled and made available to plants again.

## Van's explanation

> *"What determines organic matter quality? The most common measure of quality is the carbon to nitrogen ratio (C:N ratio) which is a measure of the relative amounts of carbon and nitrogen contained within the SOM (soil organic matter) and litter. Typical C:N ratios of common organic matter (OM) can be seen in the following table.*

*As a rule of thumb, a C:N ratio of approx 25 is somewhat of a watershed. The further the OM is above this value (ie higher amounts of carbon per gram of nitrogen) the slower will be the rate of decomposition, but the further below a C:N of 25, the faster the rate at which OM decomposes. This is why say lucerne (with its low C:N ratio) doesn't last long in the soil compared to say wheat stubble, and why it spoils so rapidly when wet.*

| Organic Materials | | Nitrogen in Dry Material (%) | | Usual C:N Range |
|---|---|---|---|---|
| **Materials** | Grasses | 1.8 | Carbon Constant | 20 - 25 |
| | Clover | 2.2 | | 15 - 22 |
| | Lucerne Hay | 3.1 | | 12.0 - 15.0 |
| | Farmyard Manure | 2.6 | | 14 - 20.0 |
| | Wheat/Oats Stubble | 0.4 | | 90 - 160 |
| | Chicken Manure | 5.5 | | 6.0 - 8.0 |
| **Soil Organisms** | Bacteria | 8 | | 3.0 - 7.0 |
| | Fungi | 5 | | 4.0 - 15.0 |
| | Protozoa | 8 | | 3.5 - 10.0 |
| | Nematodes | 4.0 - 7.0 | | 7.5 - 12.0 |
| | Soil Insects | 8.0 - 10.0 | | 5.0 - 9.0 |
| | Worms | 8.0 - 10.0 | | 3.5 - 6.0 |

Figure 32: Variations in carbon:nitrogen ratios.

***If Material contains 54% carbon and 1.2% nitrogen, its C:N ratio is 54/1.2 = 45***

*Let's follow what happens when two contrasting types of litter are added to the soil. For materials with a low C:N, such as lucerne or clover, the breakdown will begin almost immediately because there is plenty of nitrogen around, and this nitrogen is needed by the bugs to make proteins. They need the proteins to build their bodies just the way animals need proteins. The more they multiply, the more nitrogen they need.*

*In fact, there is usually more nitrogen in the lucerne than is required, so some is released into the soil and can be used by plants. The example below gives an idea of what might happen.*

*However, for say oat trash with a higher C:N ratio, nitrogen is usually not released upon decomposition, and may not become available for many months. In fact, nitrogen from the soil (which otherwise would be available for plant growth) is usually needed by the decomposing organisms to complete the job of breaking down the oat trash, ie the soil organisms remove nitrogen from the soil as they need proteins to build their bodies. In other words, if planted too soon, a following crop may show nitrogen deficiency symptoms if fertiliser is not added. The example shows why this is so. (This is why grazing out all the good, high-nitrogen plants leads to a system that can not respond as well to rain.)*

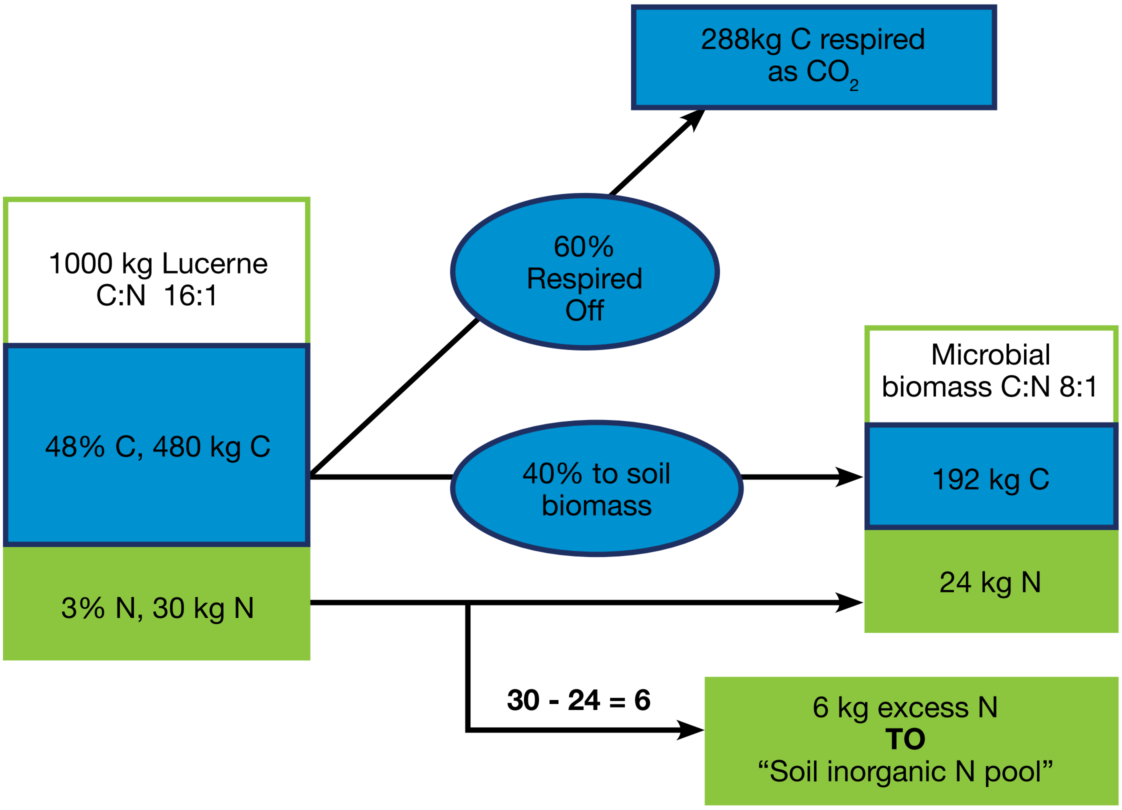


Figure 33: EXAMPLE 1 (Lucerne – C:N = 16:1).

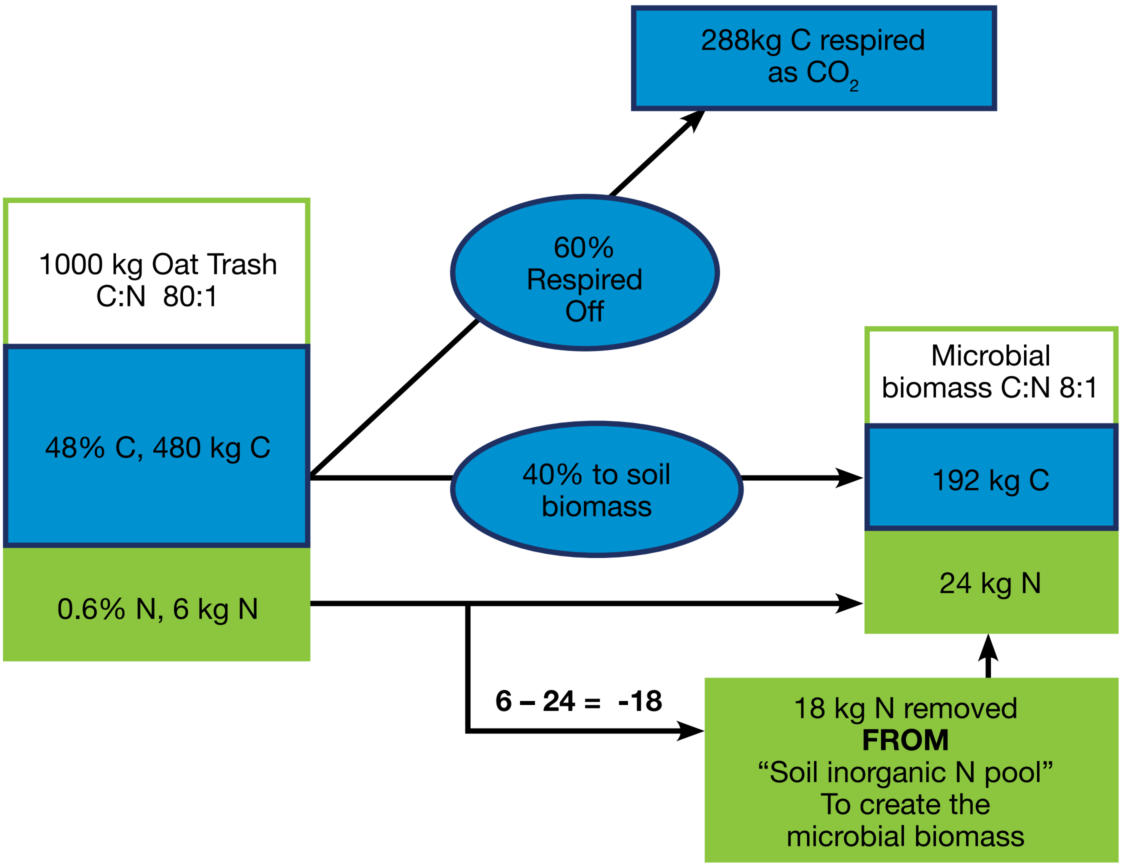


Figure 34: EXAMPLE 2 (Oat trash – C:N = 80:1).

*In a healthy, fertile soil, death of soil microbes is an absolute necessity for the movement of nutrients from undecomposed litter to plants. This is because the soil organisms have to die to release the nitrogen they contain in their bodies.*

*Here is a brief overview of the movement of nitrogen from litter, through the soil organisms to plants.*

*As you can see from the table above, the various soil organisms have different C:N ratios and are all lower than even the most nutritious plant material. When bacteria and fungi start chomping into plant debris, they don't hold their breath while they do it – they respire off some of the carbon (in fact 60% of it in the above two examples), and this immediately lowers the C:N ratio of the material that remains. Sooner or later (depending on the initial C:N ratio of the litter), the bacteria and fungi begin to use nitrogen in the litter and their populations begin to increase.*

*Now if the soil contained only bacteria and fungi, then most of the carbon and nitrogen from plant debris would end up in their little bodies, and that is where it would stay. Crop or pasture plants would hardly get a whiff. Thankfully however, there are a range of organisms that dine out on bacteria and fungi.*

*One group of organisms, the protozoa eat mainly bacteria and another group, the free-living nematodes, drool over both bacteria and fungi. As you can see from the tables, these guys have slightly higher C:N ratios than the bacteria and fungi. This is really important in nutrient cycling, because it means that they don't need all the nitrogen contained within their prey to grow, so they excrete the excess into the soil, which can then be taken up by plant roots.*

*Of course there are then predators that eat protozoa and nematodes, excrete some of the excess nitrogen, and so the process goes on to the top of the food chain – worms, beetles, grubs etc. When multiplied many millions of times, this natural supply of nutrients can provide for a large proportion of crop and pasture needs.*

*That said, we don't get something for nothing, so a continual flow of carbon through the living part of soils is essential to the functioning of this system. Of course some minerals may need to be added artificially if their removal exceeds inputs. This last point is more relevant to cropping than livestock."*

(Van Bushby, retired CSIRO scientist)

## CARBON CONSUMPTION

The process explained above reinforces the importance of carbon as the building block of life. It is always consumed as we move along the food chains. The bacteria and fungi discussed in the examples above are real gluttons at 60%.

To calculate the rate of biological activity in the soil, scientists measure soil respiration rates (ie the volume of carbon dioxide given off by soil microbes as they consume carbon compounds). The respiration rate is an indication of how much organic matter is being broken down (ie the rate at which carbon is being oxidised back to carbon dioxide).

## C:N RATIO AND ANIMAL SELECTION

After reading Chapter 12 on how ruminant animals function, and their need for "green pick", it is obvious why animals seek out the higher nitrogen C3 plants in preference to the C4 plants, as they have a lower C:N ratio. It must be stated that there is a variation of the C:N ratio within the two photosynthetic groups. Annual grasses are C3s, which is consistent with them being highly sought after.

By the time we are in drought, the animals have already selected the pick of what is available. At this stage the C:N ratio of what is available in the pasture is high and it is for this reason that livestock seek out fodder trees or saltbushes to lower the C:N ratio of their diet. Put another way, they are seeking the nitrogen/protein in the saltbushes and fodder trees to enable stomach/ruminant microbes to digest the low-quality roughage. Again, animals seek shrubs and fodder trees after frost has leached the protein out of the grass leaves. Figure 29 on page 68 of how cattle at Alice Springs selected their diet is consistent with this.

In discussing diet selection, it has to be remembered that animals will always eat unexpected plants in moderation, to source trace elements, and so achieve a balanced diet. In humans, the perfect example of this process is that some women experience cravings during pregnancy. It is their bodies telling them that they have a deficiency in something, and they need to source it.

There is a parallel in the requirements of the microbes in the stomach of ruminant animals and the microbes in the soil, which are both responsible for breaking down plant material. Both groups of microbes need nitrogen/protein to build their bodies before they can break down plant material and feed animals or plants.

This explains why animals select their diet the way they do. It also explains why they select new growth which is higher in nitrogen/protein. This animal selection of new growth (shoots) can stop plants consolidating and in extreme cases, replenishing their energy reserves.

**As a general rule, higher quality pastures result in manure that is broken down quicker in the soil**. If animals are able to select a high-quality diet as a result of good pastures, then their manure is likely to be higher in nitrogen, and will be recycled more quickly by soil microbes.

## METHANE PRODUCTION

The greenhouse gas methane is emitted by ruminant animals as a by-product of their digestive process. The less efficient the digestive process, the greater the production of methane per kg of production. Not only is “green pick” critical to maintaining animal production, but its availability influences the amount of methane produced per kg of meat or fibre produced.

Put another way, the C:N ratio of the diet effects the amount of methane gas produced per kg of meat or fibre produced. Methane is a greenhouse gas with 21 times the global warming impact of $CO_2$.

Methane and nitrous oxide are where agriculture needs to concentrate more. Apart from being a greenhouse gas, nitrous oxide is also an ozone-depleting gas. **Reduced methane production and increased carbon sequestration in the soil can both be achieved at the same time through changed management practices**. This makes it the most cost effective way for agriculture to reduce its greenhouse footprint. Reducing nitrous oxide emissions is also a management issue.

As a rule of thumb, the higher the percentage of C3 plants in a pasture, the lower the production of methane gas. For this reason, there will always be higher methane production in northern Australia than southern Australia. Regardless of the region, responsible managers and landholders contribute less to methane production through having higher quality pastures. Those with more “sustainable” pastures produce “green pick” for longer going into drought and therefore produce less methane in dry times. Finally, those with drought resistant plants like saltbushes and fodder trees have ongoing protein, so produce the least amount of methane per kg of production in dry times. Should governments decide to levy a carbon tax on animal production, it would be wise to consider that one size will not fit all.

The NAPCO feedlot, "Wangaui" west of Toowoomba, splits the energy and protein in grain using steam. In effect they are doing some of the digestive work for the cattle. They achieve better live weight gains and less methane production, because cattle get better access to the energy without wasting it. I am unsure what the carbon cost is of producing the steam. However, it would offset some of the gains.

How ruminant animals produce methane and management issues to reduce the production of methane are discussed in more detail in *Chapter 19: Carbon Grazing reduces methane*.

## MAINTAINING BOTH C3 AND C4 TO MAXIMISE ENERGY

The key outcome a farmer or grazier wants to achieve is to create an ecosystem that harvests energy efficiently. This requires multiple options (energy pathways) to capture incoming energy in the grass tier. Almost all "natural" systems configure themselves to do this, but human intervention disrupts this process. We always seem to want to simplify the system by reducing the number of input energy pathways, and thus the total efficiency of the system.

To partially restore the system's efficiency, we need to introduce more complexity into the system. This implies maintaining a mixture of C3 and C4 plants, preferably in height layers. There is a need for more emphasis on how different these two plant groups are in their manipulation of carbon, and how this can be used to advantage in establishing more energy pathways in a grazing system.

I have promoted the need for maintaining plants with higher nitrogen content, which are often missing in degraded pastures. This is to increase production and reduce methane emissions, however that is not to say that the lower nitrogen plants are not welcome. The C4 plants can photosynthesise at higher temperatures, when the C3s shut down and achieve nothing. The need is to maintain balance. Climate change is likely to change the balance between C3s and C4s in some pastoral regions, due to temperature change and moisture evaporation.

The debate on the need for both C3 and C4 plants to maximise energy flows is a continuation of "the three tiers of carbon collection". This was covered earlier in highlighting the need for a mix of grasses, shrubs and trees. It is also a continuation of the debate on how to achieve continuous "green pick".

Diverse grasslands are more capable of supplying ongoing "green pick" because they make the most efficient use of water and nitrogen when it is available. They are also more successful at maintaining the health of the landscape and making it more profitable, because carbon is being introduced and cycled more often.

## THE C:N OF SOIL IN RELATION TO HOLDING NITROGEN

We seek to increase the availability of nitrogen, but it causes havoc when it gets on the loose. If this happens, nitrogen reduces water quality, and as a volatile emission produces the worst of the greenhouse gases, nitrous oxide.

Carbon is a slow cycle, while the nitrogen cycle is a faster one, which is why it is so easy to lose nitrogen if there is insufficient carbon to hold it. When nitrogen is mineralised and dissolved in water, it can be lost very quickly if there is not enough organic matter and humus to help hold the water. Lack of aeration due to low carbon levels in degraded and compacted soils, is part of the message that greenhouse outcomes are a reflection of commercial efficiency. In these soils there is increased production of the greenhouse gas nitrous oxide ($NO_2$). Superphosphate, when over-used, or if there is not enough carbon in the soil to hold the nitrogen, often leads to acidic soils.

## SOIL NITROGEN DRIVES SPECIES CHANGE AND ALTERS C:N OF INDIVIDUAL PLANTS

A change in the mix of plant species may not just be a case of animals eating out certain varieties. Putting aside climate influences for the moment, the availability of nitrogen in the soil can also contribute to a change in the species mix of pastures. The C3 plants have a higher nitrogen requirement to construct their leaves. In a degraded landscape, C4 plants have a competitive advantage as they require less nitrogen. Degraded soils hold less water, so the C4 plants have another advantage due to their higher water use efficiency.

We can alter or improve the C:N ratio of plants through management. In general it could be said that any specific plant type in a properly functioning landscape will have a higher nutritional value than one in a dysfunctional landscape of the same soil type. The protein level of wheat changes when fertiliser is added, which is another example of this principle.

We look at the C:N ratio of different plant species as they are the start of both food chains. Yet it is the soil that plants live in that can also influence the potential C:N ratio of a plant.

**"I HAVE FINALLY GOT TO RE-READING CARBON GRAZING. HOW DIFFERENT IT IS ON THE SECOND READ. I AM CAPTIVATED AS YOU REVEAL THE "SECRETS" OF GOOD GRAZING MANAGEMENT."**

**...SHANE JOYCE, GRAZIER, THEODORE, QUEENSLAND, AUSTRALIA.**

**"ALAN HAS THE GREAT ABILITY TO THINK ACROSS SCALES FROM THE MOLECULES INVOLVED IN CARBON FIXATION, THE GREEN PICK NEEDED FOR SHEEP AND CATTLE DIGESTION, TO THE GLOBAL CHALLENGE OF CLIMATE CHANGE."**

**...DR DAVID FREUDENBERGER, FORMER CSIRO SCIENTIST, CANBERRA, AUSTRALIA.**