# How a pasture phase improves soil health and sustainability

P. Pittaway

Chrysalis Landscape Consultants, 31 Douglas McInnes Dve, Laidley Qld 4341

**Abstract.** Feeding the soil biota in a pasture phase is an investment in soil structure and the slow release nutrient bank, synchronising the availability of nutrients with the demands of crop growth

## What pastures do

Perennial pastures cover the soil for longer than annual crops, and typically, fewer nutrients are harvested and exported from the site. Under conservative grazing pressure, increased ground cover protects the soil surface from desiccation and reduces the physical impact of wind and water. The temperature fluctuation at the soil surface is less, water is conserved, and the risk of erosion is reduced. One key advantage of a pasture over an annual crop is that a mix of unrelated plant species and different ages is possible, increasing the diversity within the system, reducing the risk of pest and disease outbreaks. The very different selection pressures imposed by grazing in a mixed species stand are also very effective in controlling crop weeds that have developed resistance to herbicides.

Ground cover is equally important in providing protection, shelter and sustenance for soil organisms. Pastures are disturbed much less frequently, as plant density and grazing pressure replace the need for tillage and herbicides. As a result, the litter layer builds up, feeding soil animals and microbes.

But do plants need soil animals and microbes? Plants grow hydroponically, so, shouldn't we simply provide the basic nutrients, select suitable species for the soil type and climate, and let the plants get on with it?

Plants do indeed grow hydroponically, but water-soluble nutrients must be supplied in the correct ratios over the duration of the growing cycle. The nutrient solution must be oxygenated, and must be filtered or some form of microbial biocide added, to control diseases. The recycling of media used for germinating the plants and the nutrient solution is limited, because of the buildup of pests and diseases. To a lesser degree, these interventions and limitations apply to annual crops. By comparison, pastures are much more robust and ecologically sustainable. In this paper, I will show you that the answer lies in the soil biota, the soil animals and microbes that are the essence of soil health. Without these, we have only 'dirt'!

## Why soil health?

Health is the absence of disease, the ability of a crop or pasture to function to its full capacity within the limitations of its gene pool, and the resources allocated to it. To define the health status of a crop or pasture, prior knowledge of the capacity of the crop to grow and produce within that environment is necessary. If additional resources such as irrigation and fertilisers are to be allocated, then knowledge of the limitations of the soil type and the water supply, and the capacity of the crop to respond is necessary. In the past, soil has been viewed as a black box, into which seed is sown, fertilisers and pesticides are added, and from which food and fibre is harvested. This 'hydroponic approach' to matching inputs with harvested outputs, is not sustainable for several reasons. In broadacre farming, yield potential can vary substantially over a season, and nutrients applied can be lost to the system *via* leaching and erosion. As the cost of inputs relative to harvested outputs has increased, the need to understand and manage the 'health' of the system has also increased. Some basic functions that the soil must perform for plants to grow and thrive are:

- Large soil pores for drainage and air exchange.
- Small soil pores for storing water.
- Soil aggregate structure that encourages root penetration and exploration.
- A system that recycles organic matter back into the mineral form that roots absorb.
- A deposit and withdrawal system that retains

nutrients within the rooting zone available for root absorption.

Most of the soils classed as arable in Australia fulfilled these criteria for the first 20 years or so of farming. Over the longer term (50 years), the structure and fertility of many cropping soils has declined, despite innovations in tillage, fertilisers, pesticides, and the release of improved plant varieties. The ability of the soil to support these inputs and innovations, the soil health, has declined. Research into factors responsible for this decline has highlighted the importance of organic carbon (OC) supplies, and the biological interactions that are responsible for soil structure and fertility.

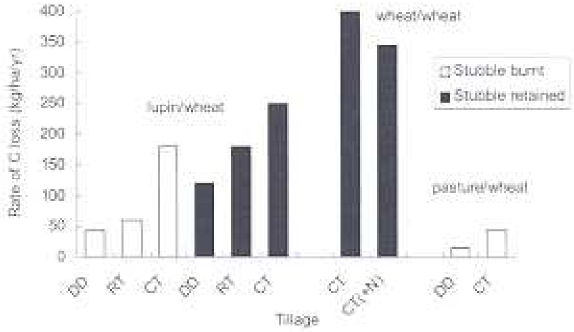


**Figure 1. The impact of crop management on the rate of loss of organic carbon from agricultural soils. Tillage included direct drilling (DD), reduced tillage (RT), and conventional tillage (CT). A pasture phase before a direct drilled wheat crop resulted in the lowest loss of organic carbon (after Chan 2001).**

## Organic carbon, the driver of soil biota

We know that management practices such as tillage and burning increase the rate of loss of OC (Fig. 1). Tillage breaks open soil aggregates, within which OC is protected from attack by soil organisms. This physically protected OC contributes to 20-40% of the total OC reserves in the soil, in the absence of excessive tillage (Table 1). Some scientists consider that the size of this longer term reserve of OC, with a turnover rate of about 50 years, regulates the size of the microbial biomass. Microbial populations increase with the addition of readily available carbon such as green manures or simple sugars, and decrease as tillage and dry conditions kill exposed cells. Life in the soil is very dynamic, with competition between organisms for OC and the effect of wet and dry cycles constantly challenging the survival of different species. However, it is the amount of the longer term fraction of OC that sets the population base of microbes. A pasture phase increases both the readily available and the longer term OC supplies in the soil.

Microbes (organisms <0.2 mm) have no teeth or gut, and must chemically degrade organic matter into smaller mineral or amino acid particles for transport across the cell wall and membrane into the cell. When plants drop leaves, or a pasture is slashed or grazed, the resulting litter is too large for microbial access. Soil arthropods (animals including the insects, having jointed legs) do have 'teeth' (mouthparts) and a gut, and are critical in breaking litter down into smaller fragments. Formed from modified legs, the mouthparts of different arthropod species can match the range of activities characteristic of the mechanical attachments of backhoes, front-end loaders and bobcats. These mini excavators move through the soil, producing the pores and channels that are essential for water infiltration, air exchange, and root growth. In the absence of a protective litter layer, and under excessive tillage or heavy grazing pressure, the populations of these arthropod recyclers (including termites, ants and springtails) are reduced. Earthworms get the best press, but in terms of diversity and tolerance to dry conditions, the activity of soil arthropods is much more significant.

**Table 1. The different organic carbon (OC) fractions found in soil. The concentration of litter is excluded, as this should be brushed aside before soil is sampled for chemical analysis. In southeast Queensland, the average concentration of OC utilised by microbes (excludes humus, charcoal and coal) in agricultural soils is 2%. Data are from Jastrow and Miller (1998)**

| Component of OC | Chemical OC fraction | Turnover rate (years) | Contribution to soil OC (% dry weight) |
|---|---|---|---|
| Fine fragments | Particulate | 5-20 | 18-40 |
| Fine fragments | Light | 1-15 | 10-30 |
| Living microbes | Microbial biomass | 0.1-0.4 | 2-5 |
| Within soil clods | Physically protected | 50-1000 | 20-40 |
| Humus | Chemically protected | 1000-3000 | 20-40 |

Starve the soil of litter and plant cover, the source of soil OC, and you lose the activity of these soil animals. A conservatively grazed pasture favours soil animals and therefore soil health.

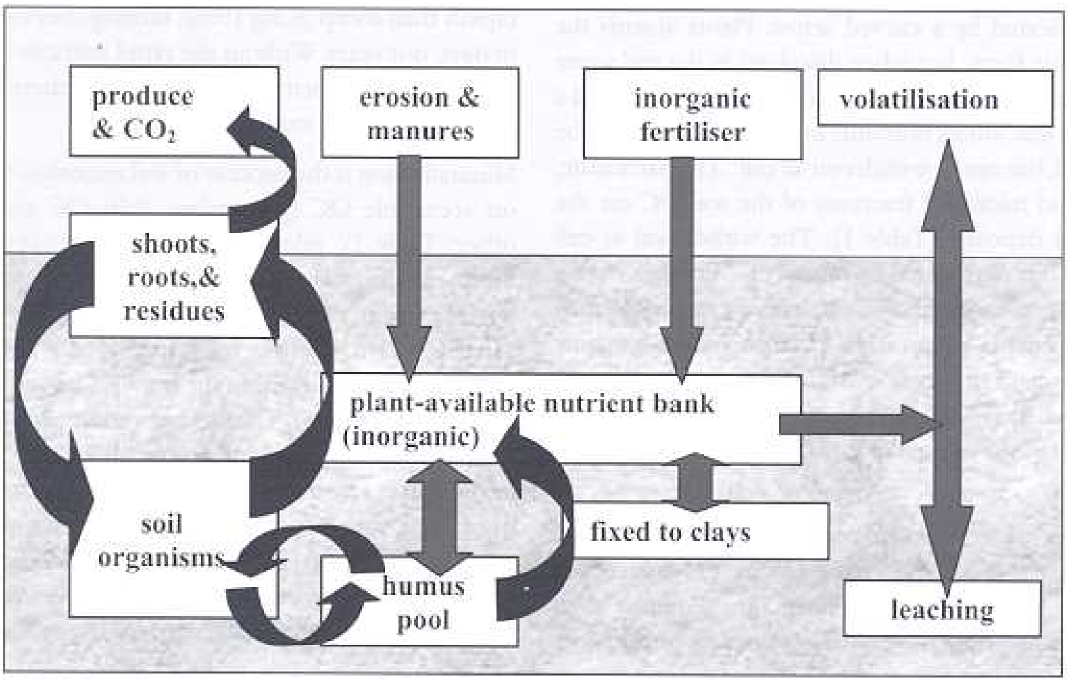
## Microbes, soil structure and crop nutrition

For microbes, all the biochemical compounds for dissolving food (saliva and bile equivalents) and disposing of waste (urine equivalent) are secreted into the space immediately outside the cell. Interacting with soil particles, these microbial secretions bind clay, silt and sand into water-stable aggregates. Some microbes (fungi) have the ability to grow from the tip of a cell, with new cells remaining attached, much like a microscopic root system. These fine filaments can penetrate small fissures in soil clods, also binding soil particles together. Just as tree roots can mechanically penetrate weeping pipes, some fungi invade plant root systems. Many pasture plants tolerate invasion by mycorrhizal fungi, because their fine filaments are able to exploit phosphorus (P) and trace element reserves locked onto sand grains or within very fine fissures in the soil that roots cannot access. The mycorrhizal filaments can transport P 2-3 times faster than a plant root system. Under reduced or no-till farming, the fungal networks established under a pasture remain available for the following crop. For species such as maize, faba bean or cotton that are dependent on mycorrhizae, as much as $500/ha in P can be provided by sowing the crop into an established mycorrhizal network (Thompson *et al.* 2003).

If the pasture contains a legume component, and the legumes are nodulated by effective strains of rhizobium bacteria, the nitrogen (N) nutrition of the following crop can also be enhanced considerably. In studies in south-east Queensland, legume-based pastures can add from 130-140 kg N/ha/year, for the next crop (Dalal *et al.* 1991). As a rule of thumb across eastern Australia, for every tonne of shoot dry matter produced by a legume crop, 20-25 kg N will be fixed (Peoples *et al.* 2001). However, if there is insufficient OC available to stimulate microbial uptake of the N, or if there is insufficient humus to hold onto inorganic N, it may be lost below the rooting zone in deep drainage.

To be available for uptake by plants, nutrients must be dissolved in the soil water. If soil water is excessive, as after a rainfall or flood event, then these dissolved nutrients can move below the rooting zone, and be lost to the crop. This process is referred to as leaching (Fig. 2). Some clay soils have an ability to bind reversibly with positively charged minerals in the soil solution, retaining them within the rooting zone. This function of cation exchange is also a property of the

Figure 2. The role of organic carbon and the soil biota in soil fertility. Without the biological activity indicated by the curved arrows, nutrients in the inorganic form (straight arrows) can be lost *via* leaching, or can be irreversibly bound to clay particles. Without the biological interactions, soil really is only dirt!



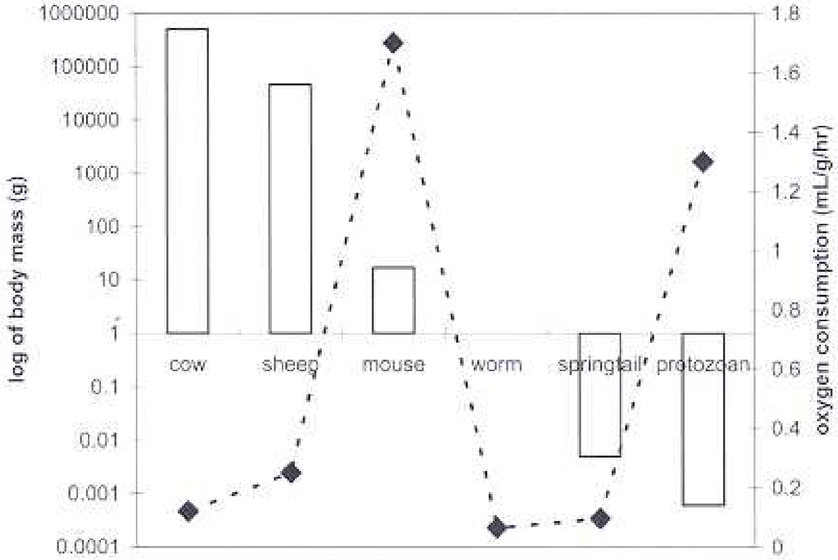


**Figure 3. Oxygen uptake rate for different animals per unit of body mass. Oxygen uptake is an indicator of metabolic activity. The higher the metabolic rate and the smaller the animal, the greater the rate of nutrient turnover. Data are modified from Prosser (1973).**

very resilient form of OC known as humus. Humus is the byproduct of microbial activity, the toughened, 'chewed and spat out' remnants of plant residues that constitutes between 20-40% of the OC reserves in soil (Table 1). In sandy soils, if the OC content is reduced, the cation exchange capacity is also reduced. Particularly in the tropics and subtropics where the combination of warm and wet favours the activity of soil organisms, OC supplies must be replenished on a regular basis to retain the structural and chemical fertility of cropping soils.

## Feeding the soil to feed the crop or pasture

Nitrogen is the only 'mineral' that can be taken 'from thin air' (N-fixing bacteria). All of the other minerals must be recycled and transformed from the organic form into a soluble inorganic form, for plants to absorb. In Figure 2, the inorganic processes are indicated by a straight arrow, the organic processes are indicated by a curved arrow. Plants absorb the inorganic form, but when dissolved in the soil water these nutrients can be lost *via* leaching. Plants need a system that stores nutrients in a form that cannot be leached, but can be withdrawn 'at call'. The particulate, light and microbial fractions of the soil OC are the banked deposits (Table 1). The withdrawal at call function is performed by microbes. Microbes have a life cycle measured in hours, with a capacity to turn over nutrients within days. Microbes constitute only a very small proportion of the OC pool (about 2-5%), but their ability to transform nutrients from the organic to the inorganic form is fundamental for soil fertility.

The rate of nutrient turnover in organisms is most commonly measured as the uptake of oxygen per unit of body weight per unit of time. Animals such as sheep and cattle lock up a large amount of nutrients in their body mass, and turn over about 0.2 mL oxygen/gram/hour (Fig. 3). Reduce the body mass to that of a mouse (a hundred thousand times smaller), and the oxygen consumption rate increases to about 1.7 mL/gram/hour. Soil animals such as worms and springtails are smaller still, but do not expend energy in maintaining a body temperature. Accordingly, their oxygen consumption is only about 0.1 mL. Reduce the body to a single cell (for example a protozoan), with a very large active surface area relative to its volume, and the consumption rate soars to about 1.3 mL/gram/hour (Prosser 1973).

Ever wondered about the concept of 5 sheep equivalents active below ground for every sheep active above ground? Soil microbes function 5 times more rapidly than sheep (King 1996), turning over nutrients in days, not years. Without the rapid nutrient storage and turnover capacity of the soil biota, there would be no pasture for stock to graze.

Mineralisation is the process of soil microbes feeding on accessible OC (particulate, light OC and each other; Table 1), releasing inorganic nutrients. The lifespan (turnover) of a microbe can be hours or days, whereas that of a sheep is measured in years. Microbes also retain a millionth of the nutrients stored and recycled within the body of a sheep (refer to the bars in Fig. 3). The concentration of nutrients stored in microbes and other accessible OC reserves in the soil is referred to as the slow release nutrient pool. The rate of mineralisation of this pool is greatest under warm and wet conditions. These conditions also favour plant growth. Synchronising mineralisation with plant growth cycles is a fundamental component of soil health. Nutrients stored in the organic form are secured against leaching, available at call for plant growth, provided there is sufficient accessible OC to fuel microbial activity (curved arrows cycling into the plant-available nutrient pool in Fig. 2).

## Managing microbes and soil animals for soil health

There are many commercial products on the market that claim to enhance microbial activity in soil. There are also many claims that commonly used pesticides and inorganic fertilisers kill microbes. Soil microbes are constantly being challenged by competitors, predators, and the rigors of extreme wet and dry cycles characteristic of broadacre agriculture in Australia. Some forms of mineral fertilisers will kill microbes on contact (acidifying fertilisers and those with a high electrical conductivity). Microbes are also likely to be killed around stock urine patches for similar reasons. However, the rates of fertiliser (and urine) application are too low to greatly affect the general microbial population, just as the rates of application of many commercial 'soil activator' products are also too low to have any measurable effect. Repeated applications of some herbicides and insecticides over the short term will have a more damaging impact on soil animals, especially where there is very little leaf litter to protect them.

The soil biota will recover, provided there are sufficient supplies of accessible OC to stimulate growth. Microbes are responsible for the breakdown of chemicals in the soil, including pesticides, and the microbial byproduct humus chemically interacts with minerals and pesticides to reduce their toxic effects. The best way to manage the soil biota is to provide sufficient soil cover to buffer the soil environment, and to diversify cropping over time to diversify the inputs of OC into the soil system. Reducing the frequency of tillage and pesticide application, and managing stock to reduce the extent of soil disturbance will also favour the activity of soil animals. Monitoring the amount of litter per unit surface area over time, comparing rates of water infiltration and the depth of the wetting front using powder paint and PVC cylinders, are simple methods that can be used to indirectly monitor the activity of soil animals. For microbes, monitoring changes in the concentration of biologically available organic carbon (Walkley & Black test from a commercial laboratory) in the soil over time, or comparing the extent of decay in calico strips buried in PVC cylinders of soil maintained at field capacity for 6 weeks or so can indicate population trends. For intensive cropping enterprises, incorporating a pasture phase is a great way to renovate the system, providing a greater opportunity for the soil biota to recover.

Feeding the soil with a pasture phase and maintaining an effective litter layer is an investment in soil health, and in the longer term economic and environmental sustainability of agriculture.

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