SOIL BIOLOGY 101 FOR POTATO GROWERS

Soil biology is a key driver for nearly all functions within the soil. Biological activity affects soil structure and aeration, nutrient cycling and availability, breakdown of organic materials, plant growth and disease.

Dr Jenny Ekman reports

Fungi, bacteria and other soil dwelling organisms are what build soil structure. Their activity creates the air pockets that allow potato plant roots and tubers to breathe. Those same spaces also allow water to infiltrate soil, holding it where it's available for plant growth. In contrast, structureless soils are likely to form a crust, so that water just runs off.

Tillage breaks down soil aggregates into smaller units. Regular tillage also tends to favour bacteria over fungi, as it breaks up the strands of fungal hyphae in the soil. Populations of larger soil dwellers such as nematodes, worms, insects and mites are also reduced by regular tillage.

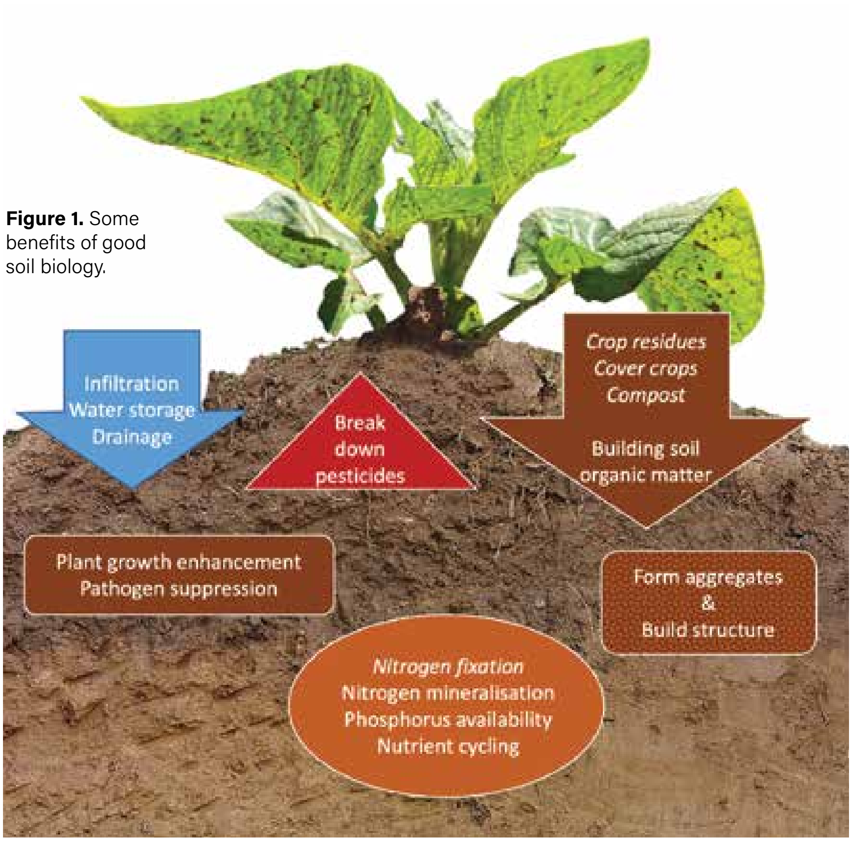

Figure 1. Some benefits of good soil biology.

SOILS TEEM WITH LIFE

Vegetable growing soils are rich in microbial life. There may be hundreds or even thousands of different species of bacteria, fungi and eukaryotes ('critters'). Even worn-out soils can still contain large numbers of different organisms.

Dr Kelvin Montagu has been examining the range of organisms present in soils used to grow vegetables and potatoes. "Soil from a potato farm in Forthside contained more than 500 species of bacteria, 200 species of fungi and 50 species of critters (e.g. nematodes, worms and springtails)".

"Even worn-out soils still have big microbial populations. For example, we worked on a farm in South Tasmania that was completely thrashed. Compared to some of the other farms we tested, there were a lot more species of bacteria than fungi present in the soil (Figure 2). This likely reflects regular cultivation. Despite this, significant populations of fungi and critters still remained, so the soil can be rehabilitated."

Soil biology means that when a potato seed sprouts, it is not into an empty space, but one already full of other inhabitants. As the shoot starts to grow into the soil, cells are shed from the root tips and exudates are

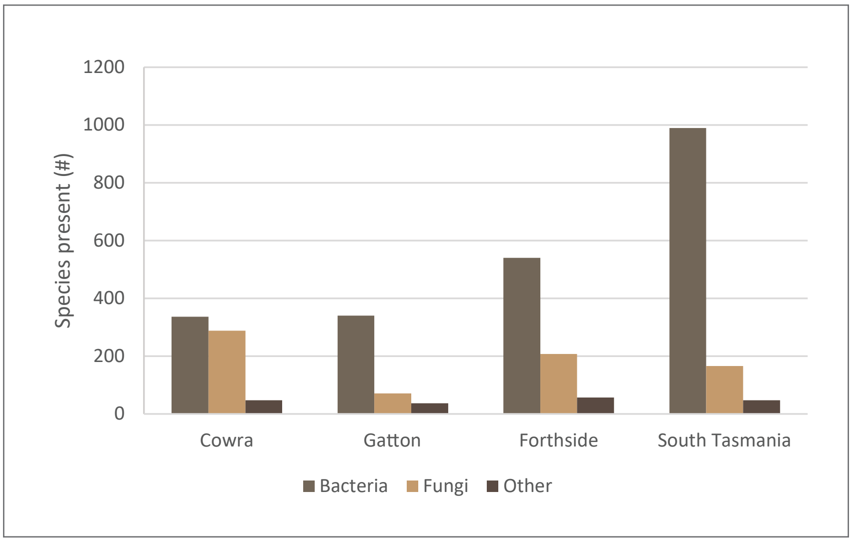

Figure 2. Number of species of bacteria and fungi and other phyla (e.g. nematodes, mites, insects) in soils used to grow potatoes and/or vegetables. - Data from K. Montagu

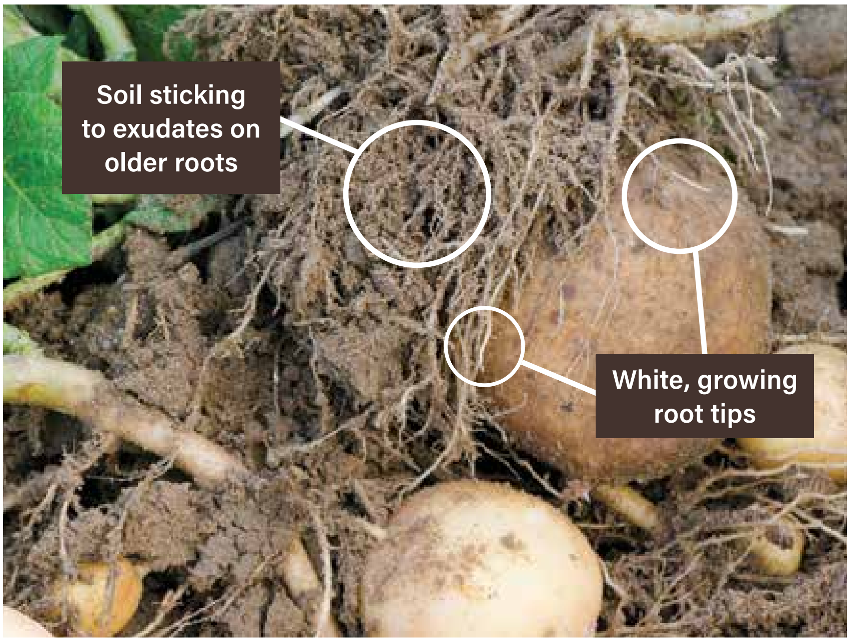

Figure 3. Roots and their surrounds are a biological hotspot

Figure 4. Mycorrhizal fungi can help plants capture more nutrients from the soil. - UC ANR.

N.B. Mycorrhizae are not usually visible to the naked eye

released. These attract specific fungi and bacteria – which may be either beneficial or pathogenic.

After a few days of expansion the roots shed their fine hairs and form a waxy coating. Microbes become embedded in sticky compounds exuded from the surface, forming a barrier around the roots (Figure 3).

This means that beneficial organisms need to be already in the soil, ready to colonise the young potato plant right at planting. Otherwise, the young roots can be swamped by other organisms.

The benefits of mycorrhizal fungi to plants are well established. They improve moisture and nutrient uptake and can help to protect against disease.

Mycorrhizae live on carbohydrates produced by the plant. In exchange, they provide the plant with phosphorus and other nutrients from the soil (Figure 4).

Cultivation reduces natural populations of mycorrhizal fungi, which are often low in vegetable growing soils. Moreover, if the soil contains high levels of available phosphorus, the plant doesn't need its mycorrhizal partner, so the fungi may fail to establish.

HELPING THE GOOD GUYS

The two main things needed to activate soil biology are:

1. **Structure** – building them somewhere to live, with the right balance of air and water
2. **Food** – providing the raw materials needed to feed soil organisms

Bulk food includes crop residues, pasture (including roots) and cover crops incorporated into the soil. "These materials are like Weetbix for soil fungi, bacteria and earthworms. They use them as carbon sources as well as for the sulphur, phosphorus and other nutrients they contain" explains Dr Montagu. "Bulk feeding is incredibly important for improving soil structure. As bacteria and fungi feed on these materials they excrete the proteins and sugars that bind the soil particles together. Essentially, the microbes help build their own house."

Soil organic matter is a great indicator of soil health. Two of the best ways to increase soil organic matter are through use of cover crops and including pasture in the rotation.

It's possible to manage how quickly organic materials break down in the soil through crop selection, as well as manipulating the carbon:nitrogen ratio.

Dr Montagu gave the example for a cereal rye cover crop. "Terminating two weeks later than originally planned increased biomass from 7 t/ha to 9 t/ha as well as changed the C:N ratio from 30 to 45. The result was a much slower breakdown after incorporation into the soil."

"Wheat stubble has a C:N ratio close to 80, so it's really slow to break down. What's more, soil microbes may initially take nitrogen from the soil to help break down the stubble, making it unavailable to the plant. At the other end of the scale, a legume such as vetch has a C:N ratio of 15, so it breaks down extremely rapidly" explained Kelvin.

High C:N ratios favour fungi over bacteria. While fungi are slower, they convert more of the crop residue into soil organic matter, so effectively yield more soil organic matter for the same biomass inputs.

Soil microbes not only break down organic matter, but they are also vital to breaking down agrichemicals. Many chemicals would persist much longer in the environment if no biological activity is present. Essentially, the microbes use such chemicals as sources of nitrogen, carbon and other nutrients.

According to Dr Montagu "A side effect of repeated use of some agrichemicals is that you effectively select for microbes that feed on them. So they will be there in the soil, waiting for their next feed of metham sodium, or pre-emergent herbicide, or whatever.

The result is reduced chemical efficacy, because the biology breaks those products down so fast they aren't able to work."

Figure 5. Volunteer potatoes are a major issue, as they allow soil borne disease to persist. - R. Barrett.

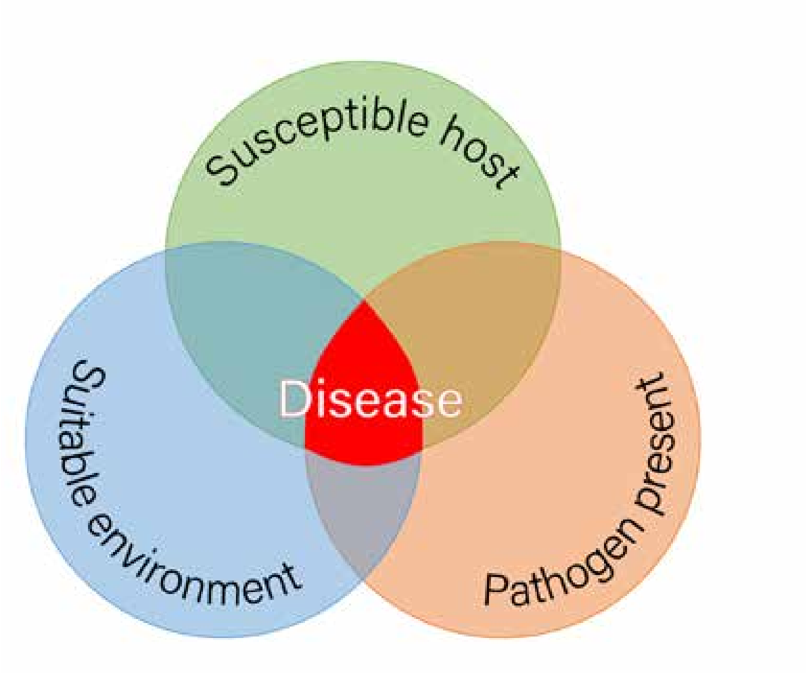

Figure 6. For disease to occur, the potato plant must be susceptible, pathogen present and environment suitable for infection – the classic "Disease triangle".

FIGHTING THE BAD GUYS

Just as the soil is rich in beneficial microbes, it is also inhabited by those that would do potatoes harm. Nematodes, bacteria, fungi, protists (such as powdery scab) and even viruses are ready to pounce on an unprotected potato plant and proliferate at its expense. Some are potato specialists (e.g. powdery scab and pink rot), whereas others have a broad range of hosts (e.g. *Sclerotinia*, *Rhizoctonia*).

Dr Calum Wilson is a plant pathologist and expert on soil-borne diseases of potatoes. "Most pathogens that multiply on potatoes die off if the

40 days

68 days

92 days

Figure 7. Breakdown of a ryegrass green manure crop in Cowra 40, 68 and 92 days after spraying out with glyphosate. - M. Hinderager.

potato or an alternative host is not there. This is the basis of crop rotation" states Dr Wilson.

"However, some diseases are good at surviving between potato crops, either by having a broad host range, or persisting on decaying organic matter. Certain pathogens form resting structures that can persist in the soil for years – powdery scab is particularly difficult to control due to this factor. Pathogens can also hitch a ride on contaminated seed, which is why clean seed is so important."

Volunteer potatoes are another big problem (Figure 5). According to Dr Wilson, volunteer potatoes are one of Tasmania's worst weeds; "if there are volunteer potatoes within the rotation, all you are doing is following a good potato crop with a bad one. That's why managing volunteers is critically important for disease control".

In general, poor soil biology favours infection. Poor soil structure reduces drainage and aeration, extending the time plants stay wet. Plants grown in non-biologically active soils are more likely to be stressed, making them susceptible to disease. Finally, low biological activity means there is less competition from other microbes compared to a soil with high organic matter. This can make it easy for the pathogen to persist and spread.

"Green manures, composts and cover crops all help improve soil biology, while tillage is frequently disruptive, especially to fungi," commented Calum. "Encouraging the beneficial soil microbes helps control the bad guys, as they will feed on them."

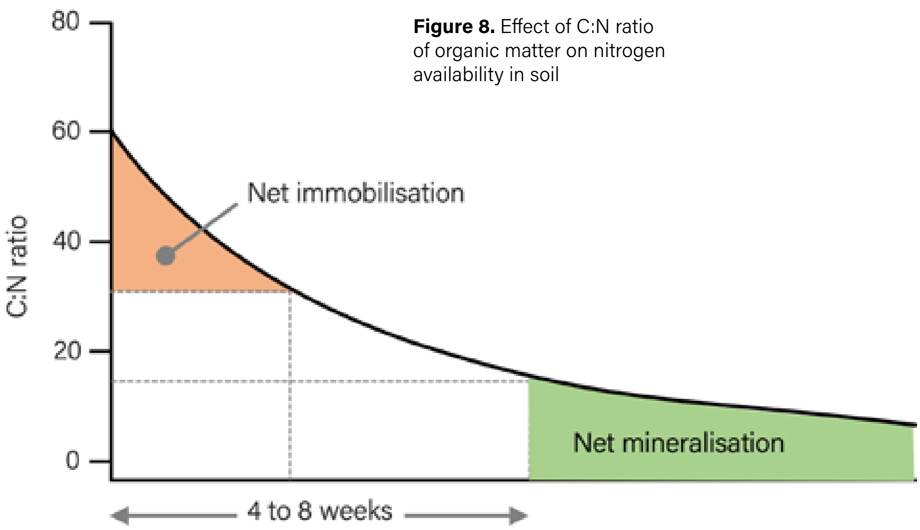

Figure 8. Effect of C:N ratio of organic matter on nitrogen availability in soil

BALANCING SOIL BIOLOGY AND PLANT NUTRITION

Plants need nitrogen

Potatoes require balanced nutrients, and that includes a lot of nitrogen. Some varieties will use over 30kg of nitrogen a week during their early bulking stages, so that means somewhere between 150 to 300kg N/ha, depending on variety.

Estimating soil nitrogen requirements relies on three things:

1. **Available nitrogen within the root zone**
   - Requires strategic soil testing for inorganic nitrate and ammonium
2. **Soil organic carbon**
   - Estimate of in-season mineralisation
   - Test for organic matter, pH and CEC
   - Understanding the environment, including temperature, moisture and aeration in combination with soil biology

3. **Previous crop residue**
   - Estimate whether nitrogen will be tied up or released as crop residue degrades
   - Amount of dry matter in the residue, its condition and position within the row
   - Effects of climate and soil biological activity

Standard practice for soil testing is to sample the top 30cm. However, according to AHR agronomist Marc Hinderager, conducting separate tests of the top 0 – 15cm and 15 – 30cm gives far more information. "This is really useful if you're coming out of long-term pasture, or making decisions on whether to add soil amendments such as compost," suggests Marc.

NITROGEN IS UNLOCKED BY SOIL BIOLOGY

The conversion of organic nitrogen sources to nitrate depends on the activity of microbes in the soil. This process starts at around 5°C, accelerates as it approaches 20°C and peaks between 30 and 40°C. Between 50 to 125kg N/ha can be mineralised annually from Australian soils, although ten-fold fluctuations are not uncommon.

"This means that soil tests are just a snapshot in time. It's important to consider this when estimating how much N the crop needs as the plants grow," commented Marc, "especially when considering breakdown of organic materials."

"For example, at our Cowra site we knocked down a green manure crop of ryegrass with glyphosate in mid-September. Ryegrass has a C:N ratio of 20:1. Combined with warm temperatures and 200mm of rain, this meant it was rapidly broken down by microbes (Figure 7)."

"By early December 60% of the organic N had been mineralised, effectively recycling 60kg N from the 100kg organic N contained in 2.5t/ha ryegrass residue. If the ryegrass had been incorporated, rather than left on the soil surface, it would have broken down around 10-15% faster".

At the same time as mineralisation is occurring, so is immobilisation. This is also driven by soil biology, in combination with temperature and moisture.

Crop residues with C:N ratios above 25:1 (like wheat stubble) will initially immobilise (tie up) soil inorganic nitrogen, making it unavailable to the plant (Figure 8). The factors that drive soil biology – temperature, moisture, aeration, pH and soil organic matter content – all influence the time taken to remobilise nitrogen, resulting in net mineralisation.

The biological activity within the soil can be estimated by measuring respiration. Microbes within the soil respire, absorbing oxygen and releasing carbon dioxide. The rate at which this is occurring reflects metabolic activity.

Sealing a portion of soil inside a container and measuring atmospheric changes provides an indicator of total microbial activity.

NITROGEN FROM LEGUMES

"As the price of fertilisers has increased, a lot of my farmers have been getting more interested in legumes," says Marc. "Legumes can fix around 20kg of N per tonne of dry matter, so long as good nodulation occurs. The roots can add another 35%. However, if the seed is harvested as a cash crop, that reduces fixed N to around 13kg/tonne".

Getting the right strain of Rhizobium bacteria is essential to get good nodule formation. Just as roots of potato plants signal to mycorrhizal fungi, so do the roots of legumes to Rhizobium.

Although Rhizobium are naturally present in soil, artificially inoculating seed with a good strain of Rhizobium will usually pay for itself. Commercial Rhizobium strains have been bred for effectiveness, and provide more reliable results than native Rhizobium in soil.

The total N fixed by legumes is also affected by soil nutrition. Good levels of molybdenum and a neutral pH help optimise results. Some research has indicated that phosphate and potash increase both the number of nodules, and the amount of N fixed (Figure 9).

Conversely, acid soils reduce N fixation for most legumes. Lupins are an exception, as they prefer acid soils.

Figure 9. Nodules on roots of legume - Neutrog Fertilisers

	Urea (CH_4N_2O)	Ammonium (NH_4^+)	Nitrate (NO_3^-)
Transformation in soil	Enzymes convert urea to ammonium.	Ammonium converted to nitrate by bacteria.	Bacteria convert nitrate to gas in warm, waterlogged conditions.
Plant available and efficiency	Can be taken up as a foliar. Limited availability (1-5 days) to roots due to rapid conversion to volatile ammonia by urease enzyme in soil.	Immobile in soil. Can be taken up directly. Potatoes prefer combination of ammonium and nitrate.	Mobile in soil (so can leach out). Can be taken up directly, potato plants.

Table 1. Biological processes and commercial fertilisers

High soil plant available N (>35kg/ha or 20ppm) will reduce N fixation by a similar amount; effectively, the rhizobia get 'lazy' if N is already abundant.

According to Marc, "Rhizobium species are the most proven biological product on the market. Peat inoculants should be kept cool and dry – in the refrigerator is good – and used as soon as possible after mixing with water to get best results. Just remember that some seed dressings and some chemical fertilisers can be toxic to them, so be careful of that".

NITROGEN FROM COMMERCIAL FERTILISERS

Nitrification is the conversion of NH_3 (ammonia) and NH_4^+ (ammonium) to NO_2^- (nitrite) and then to NO_3^- (nitrate). This mobilises nitrogen, turning it into the form most easily taken up by plants, but also potentially allowing it to leach into the environment. The process occurs rapidly in warm soils, so at 20°C a top dressing of ammonium sulphate will be converted to nitrate within a week.

Nitrification is driven by soil bacteria, including species of *Nitrosomonas*, which converts ammonia to nitrite, and *Nitrobacter*, which converts nitrite to nitrate. The bacteria are sensitive to low soil pH (pH<6), which is close to the optimum pH range for potatoes of pH 6.3 to 6.8. Managing pH is therefore essential to allow nitrification to occur.

Stabilised release fertilisers slow down nitrification by soil bacteria. This reduces nitrate leaching and emissions of nitrous oxide, making more nitrogen available to the plant and reducing the total number of top-dress applications required.

For more information on biological processes and fertilisers, a fact sheet is available on the Soil Wealth site at www.soilwealth.com.au/resources/fact-sheets/quick-guide-to-farm-nitrogen

WATERLOGGING SENDS NITROGEN BACK TO THE AIR

De-nitrification is the process by which nitrate is converted to nitrogen gas and lost from waterlogged soil. This process depends on soil bacteria and fungi – starved of soil oxygen, they utilise the oxygen in NO_3^-. De-nitrifiers are most common in the top layers of soil and active at above 15°C, especially if the soil remains waterlogged for 36 hours or more.

IN SUMMARY

A healthy soil is full of life. Bacteria, fungi, insects and larger creatures such as earthworms, all have a role to play in maintaining a healthy and productive soil. Biologically active soils will have better water infiltration and soil structure, improved nutrient management, and help potato plants resist the inevitable attack of soil-borne diseases.

Improving soil biology is not necessarily easy, especially given the tillage which is standard practice within commercial potato production. However, using suitable rotations, establishing cover crops, managing nutrition and avoiding soil becoming overworked or waterlogged can all help valuable soil microbes flourish.

As the silent workers in the field, they are well worth cultivating.