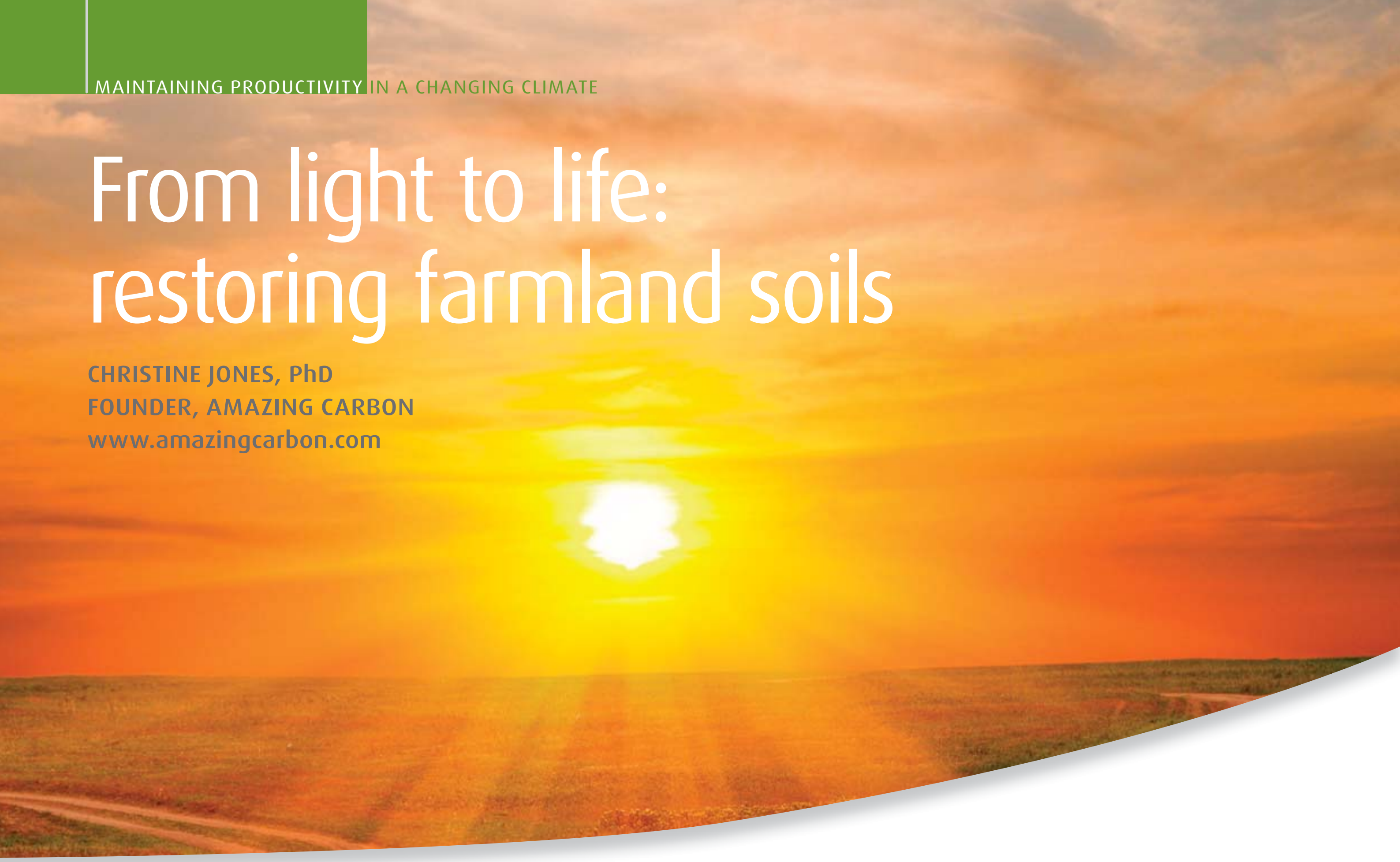

From light to life: restoring farmland soils

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Solar isn't just for rooftops. It builds soil too!

It may come as a surprise to many to find that in healthy soil there is a poor relationship between plant productivity and the amount of applied nitrogen (N) or phosphorus (P). Recent research undertaken by Dr David Johnson and his team at New Mexico State University (NMSU) found there are other factors of much greater importance.

What are these factors? And what can farmers do to optimise them?

The NMSU researchers discovered that plant growth is highly correlated with how much life—and what kind of life—is in the soil. In fact, microbial community structure, particularly the ratio of fungi to bacteria, had significantly more influence on yield than the concentration of inorganic N or P (Johnson *et al* 2012).

Given that flourishing communities of beneficial soil microbes are the 'key' to plant production, what is the secret to ensuring the right microbes are present in the right amounts?

Plants. That's right. The most important factor for promoting abundant plant growth is to have green plants growing in the soil all year round.

The plant–microbe–soil connection

You may have heard that 'plants take from the soil'. Nothing could be further from the truth. Observe what happens in bare soil. It dies. Then it blows or washes away.

If you could 'see' what happens around the roots of actively growing plants you would want to have as many green plants in your soil for as much of the year as possible.

The NMSU researchers found that planting diverse cover crops between cash crops resulted in better yields than the use of synthetic fertilisers. And that wasn't all. Soil tests showed that the availability of essential minerals and trace elements increased.

How does it work? Carbon inputs from living plants support the microbial activity required to improve soil structure, increase macro- and micronutrient availabilities and enhance soil water-holding capacity. In turn, these factors improve plant productivity. It's a positive feedback loop.

The NMSU research team found that as cover crop density increased, the effect became quadratic, due to the synergies between living plants and soil microbial communities. **That is, 1 + 1 = 4.**

It all starts with photosynthesis

The energy needed to maintain flourishing soil ecosystems begins as light. This energy must cross two bridges in order to recharge the soil battery.

First, the photosynthetic bridge. In the miracle of photosynthesis, light and CO_2 are transformed to biochemical energy (carbon compounds) in the leaves of green plants.

Second, the microbial bridge. In the presence of beneficial bacteria and fungi photosynthetic rate increases and carbon 'flows' from plant roots into soil microbial intermediaries.

If one of these bridges has been blown (e.g. no green plants or compromised microbial communities), soil health declines.

Every summer, around 22 million hectares of wheatbelt soils lie bare across eastern, southern and western Australia. Herbicides are commonly used to maintain the soil in a plant-free state. Bare ground and low levels of biological activity result in declining structure, reduced infiltration, poor moisture retention, inadequately buffered pH and an open invitation to weeds.

Take a step back in time...

Most of the temperate regions currently used for crop and pasture production supported vigorous, diverse groundcover at the time of European settlement. Summers in the southern half of the Australian continent have been hot and dry for thousands of years, yet there were more summer-active than winter-active plants in the original vegetation. This is an important point. It is not 'natural' for the soil to be bare over summer (or winter, for that matter).

Despite successive months of summer temperatures above 100° Fahrenheit (37°C) and little or no rain, observers of the original groundcover reported it to remain remarkably green (Presland 1977). Active growth was possible during hot dry periods because soil had high water-holding capacity.

After many decades of bare ground over summer—every summer—the water-holding capacity of our agricultural soils has significantly declined.

The original groundcover contained more broadleaved plants (forbs) than grasses (Lunt *et al* 1998). Nutritious summer-active native legumes within genera such as *Lotus, Hardenbergia, Kennedia, Cullen* (formerly *Psoralea*), *Glycine* and *Desmodium* were once abundant in their respective endemic areas, as were many food plants used by indigenous people, including yam daisies *(Microseris)*. As a general rule, broadleaved plants are more important than grasses for microbial diversity and nutrient cycling.

Not surprisingly, the most palatable and mineral dense summer-active plants quickly disappeared from the original groundcover due to unmanaged grazing.

Restoring soil function

The more closely we can mimic the structure and function of year-round species-rich groundcover, the more productive and 'problem-free' our agricultural enterprises will be.

If there is sufficient moisture to support summer weeds there is sufficient moisture to support a summer cover crop. Furthermore, it is **generally cheaper to sow a summer cocktail than to spray weeds**. The purpose of a multi-species cover crop is to restore below-ground diversity which will in turn restore biological soil function (natural N-fixation and P-solubilisation) and plant productivity.

The nutrient sourcing and moisture retention benefits of diverse cover crops will continue to build in successive years as soil health improves.

Summer cocktails

Examples of broad-leaved plants that can be used in multi-species summer cover crops (cocktail crops) include sunflowers, buckwheat, chick pea, sunn hemp, amaranth, cowpeas, soybean, safflower, camelina, sugar beet, squash and lab-lab. These can be combined with a range of plants from the grass family, including pearl and proso millet, sudan grass, forage sorghum, maize etc. Aim for at least 10 species or varieties in your mix, with more broadleaved plants than grasses.

Summer cocktail of sunflower, maize, soybean, cowpea, camelina, sugar beet, sudan grass, pearl millet, proso millet, pasja turnip, tillage radish, sweet clover and squash on Menoken Farm. Cover crops can be either grazed or rolled while green, prior to the sowing of the follow-on crop.

PHOTO COURTESY JON STIKA, NRCS.

The greater the diversity of plants the more checks and balances for pests and diseases and the more extensive the range of microhabitats for the soil organisms involved in nutrient acquisition, nutrient cycling and soil building (Taheri 2012).

Will there be a yield penalty?

Yield penalties may be observed in crops following summer groundcover if:

i) the summer groundcover did not include a diversity of broadleaved plants (aim for more non-grasses than grasses); and/or

ii) high rates or inorganic N (e.g. urea) or P (e.g. MAP, DAP) were applied to either the cover crop or the follow-on crop, damaging the 'microbial bridge.

Note: If inorganic N has been applied previously, for several years in succession, N use must be reduced **slowly**, as populations of free-living N-fixing bacteria will initially be very low.

What's N got to do with it?

Aside from water, nitrogen is frequently the most limiting factor to crop and pasture production.

Nitrogen is nitrogen, irrespective of the source, but the same nitrogen compounds can have opposite effects, depending on the way they enter the soil and the form in which they exist in plants.

This paradox has created much confusion.

It is neither natural nor healthy for crop and pasture plants to contain high levels of inorganic nitrogen (nitrite, nitrate etc). Nitrogen is much safer and more productive when in an organic form.

Closing the nitrogen loop

The efficiency of use of applied N is generally less than 50% due to losses from leaching, volatilisation and denitrification (Kennedy *et al* 2004). These inefficiencies cost farmers a great deal of money as well as contributing to environmental pollution.

Fortunately, biological N fixation is a spontaneous process when adequate carbon is available under actively growing plants, provided large amounts of synthetic N have not been applied. In biologically active soils, sugars and other carbon compounds exuded by plant roots support vast colonies of beneficial fungi and bacteria, which in turn produce sticky substances that glue soil particles together and enhance soil structure.

Once aggregates (small lumps) start to form, free-living nitrogen-fixing bacteria, which require a low partial pressure of oxygen, can begin their work of fixing atmospheric nitrogen. These bacteria are called associative diazotrophs—'associative' because they are only found inside aggregates attached to living plant roots or connected to plants via the hyphae of mycorrhizal fungi—and 'diazotrophs' because of their ability to use nitrogenase enzymes to fix diatmospheric nitrogen (N_2).

The nitrogen fixed by associative diazotrophs does much more than support plant growth. It also makes a significant contribution to the soil foodweb and is essential to the formation of stable forms of soil carbon, such as humus.

In addition to associative diazotrophs, mycorrhizal fungi are indispensable for closing the nitrogen loop. Their ability to transfer organic N from the soil foodweb into plant roots, circumvents the need for nitrogen to be present in an inorganic form (Leake *et al* 2004, Leigh *et al* 2009).

The activities of mycorrhizal fungi also contribute to the rapid sequestration of soil carbon.

But here's the rub.

The application of large quantities of inorganic N—such as found in urea, MAP, DAP etc—inhibits the activities of both associative diazotrophs and mycorrhizal fungi. Long-term use of these products results in a decline in soil structure, decline in soil carbon—and ironically, a decline in soil nitrogen (Khan *et al* 2007, Mulvaney *et al* 2009).

Reducing N dependence

Where diverse summer cover crops are being grown to support soil microbial communities, it is advisable to reduce N use, but this must be done slowly, to provide time for free-living N-fixing bacteria to re-establish. There is no need for synthetic N in the cover crop provided a variety of broadleaved plants, including legumes, are present.

Nitrogen inputs in follow-on crops can be reduced to 80% in the first year, 50% in the second year and 20% in the third year. In fourth and subsequent years, the application of a very small amount of N (around 1kg/ha) will help to prime the natural nitrogen-fixing processes in soil.

Remember, associative diazotrophs (the most important of the free-living N-fixing bacteria) and mycorrhizal fungi (needed for N transfer to plants) have only one energy source—liquid carbon from an actively growing green plant. At the same time as you are weaning your soil off synthetic N you must also be maintaining as much diverse year-round living groundcover as possible.

Will I need to add P?

Plant roots produce hormones called strigolactones that control root extension, lateral root development and the production of root hairs. The presence of strigolactones in soil also stimulates root colonisation by mycorrhizal fungi (Czarnecki *et al* 2013). Vigorous root systems and symbiotic relationships with mycorrhizal fungi are essential for maximising the ability of crop plants to obtain water, nitrogen, phosphorus, potassium, sulphur, calcium, magnesium and a wide variety of trace elements such as zinc, copper, boron, manganese and molybdenum.

Many of these elements are essential for resistance to pests and diseases and resilience to climatic extremes such as drought and frost.

The application of large quantities of water-soluble P, such as found in superphosphate, MAP, DAP etc inhibits strigolactone production by plant roots. That is, the use of these products will reduce root extension, root hair development and colonisation by mycorrhizal fungi. The long-term result is destabilisation of soil aggregates, loss of porosity, reduced aeration, increased soil compaction and mineral-deficient plants.

In addition to having adverse effects on soil structure, the application of inorganic phosphorus is highly inefficient. Around 80% adsorbs to aluminium and iron oxides and/or forms calcium, aluminium or iron phosphates, which, in the absence of microbial activity, are not plant available (Czarnecki *et al* 2013). Only 10–15% of fertiliser P is taken up by crops in the year of application.

In old and deeply weathered soils, biological processes are more important than chemical processes when it comes to making nutrients available to plants.

Your soil already contains sufficient P, but it will only be in a plant-available form when the right microbes are present. If levels of mycorrhizal colonisation are high, there will be no need to add large quantities of inorganic P.

Cover crops (and follow-on crops) can be supported with biology-friendly products such as pelletised compost or liquids such as compost extract, worm leachate or milk. Compost extract containing around 1kg/ha (no more) of each of N, P and S, plus whatever trace elements are required (as determined by plant tissue test) should be sufficient in most situations.

Strategic grazing

Land can respond positively to the presence of animals, but the way they are managed is extremely important. Strategic (high density, short duration) grazing of summer groundcover helps to stimulate biological activity and cycle nutrients tied up in plant material. Aim to graze no more than one third to one half of the biomass, using mob stocking or strip grazing techniques to ensure the soil surface is completely covered with trampled plant material (Jay Fuhrer, *pers. comm.*).

Rolling cover crops

If grazing is not an option, cover crops can be rolled while still green. Millions of hectares of cover crops are rolled in no-till systems across Paraguay and Brazil (Rolf Derpsch).

'Knife' or 'crimp' rollers consist of a hollow drum mounted with angled steel ridges designed to crush plant stem bases and lay the material flat on the ground. The drum can be filled with water to add weight. The follow-on crop is sown in the same direction as the cover has been rolled. Rollers can be purchased or manufactured on-farm.

Where grazing is not an option, cover crops can be rolled. Menoken Farm.
PHOTO COURTESY JAY FUHRER, NCRS.

Soil responds positively to the presence of appropriately managed animals. Here a mob of dry ewes recycles nutrients and stimulates soil biology by grazing and trampling a cocktail cover crop on Menoken Farm.
PHOTO COURTESY JAY FUHRER, NCRS.

Putting it all together

- Changing fertiliser practice alone is not sufficient to improve soil health. Unless biology-friendly fertilisers are used in combination with diverse year-round living cover the essential microbes won't be there to be supported.
- For the same reasons, the presence of summer groundcover alone is not sufficient—indeed it may prove detrimental. There will be a tie-up of N and a yield penalty in the follow-on crop unless key functional groups, particularly the associative diazotrophs and mycorrhizal fungi, are working together. This simply cannot happen if large amounts of inorganic N or water-soluble P are applied.
- Strategic grazing of summer groundcover helps cycle nutrients tied up in plant material. Aim to graze no more than 30–50% and trample the remainder onto the soil surface. If grazing is not an option, cover crops can be rolled while still green.
- There is no need for either synthetic N or P in your 'summer cocktail' provided a good range of broadleaved plants, including legumes, are present.
- Remember to wean off N slowly in the follow-on crop. Cut back to 80% in the first year, 50% in the second year and 20% in the third year, then maintain levels at 1 kg/ha/yr. If you feel you must, also apply 1 kg/ha/yr of inorganic P and 1 kg/ha/yr of S—but no more!
- Improved weed management is one of the many benefits of integrated land management. Most crop and pasture weeds are stimulated by nitrate. The current farming model is essentially creating the problem. Weeds become less of an issue under biological forms of cover cropping. This is partly to do with groundcover but more usually the result of closing the nitrogen loop.
- Above all, the capacity of the soil to absorb and hold water is critical for dryland crop and pasture production. Although it may seem counter-intuitive, the most effective method for improving soil structure and increasing water-holding capacity is to maintain active year-round plant cover, which increases soil carbon, supports microbial activity and improves the ratio of fungi to bacteria.

From light to life

Diverse summer cover crops sown with biology-friendly fertilisers are the fastest way to restore soil function in wheatbelt soils. These principles also apply to dairy, beef, lamb, wool and horticultural enterprises in the winter rainfall zone.

Sunlight intercepted by bare earth is converted to heat energy, driving evaporation and soil loss.

Sunlight intercepted by green leaves is converted to biochemical energy, fuelling soil life, enhancing soil structure, improving nutrient cycling and increasing water-holding capacity.

Why not turn 'light' into 'life' on your farm?

Perhaps just try one paddock to begin?

Your soil will love you—and you will love your soil.

'Weeds become less of an issue under biological forms of cover cropping. This is partly to do with groundcover but more usually the result of closing the nitrogen loop…'

Further information

For further information on the benefits of multi-species cover cropping see...

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