



Biologically Priming Soil

Opportunities to Build Resilience and Productivity in cropping systems

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Figure 1 The author

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Executive Summary

Modern cropping systems have generally overlooked the sophisticated biological relationships that plants have evolved to survive. In many cases, our modern methods disrupt these beneficial pairings. We are then bound to volatile synthetic inputs, and find we are operating in a degraded soil system. This has led to a merry-go-round of costly interventions for farmers and environmental impacts. Can we farm with the benefits of both worlds?

Healthy soils are the foundation of farming. But increasingly, we're facing challenging seasons, input prices and whims of the markets. Biologically priming soil is the act of encouraging or manipulating the biological conditions around a seed or plant to kickstart natural processes that offer a path to resilience and production.

Biological priming is the intentional intervention at critical growth stages, specifically at germination, to kickstart the symbiotic relationship between plants and microbes. It is the "colostrum" for the seed. Just as a livestock producer would never deprive a newborn animal of that essential package of nutrition, immune signals and microbiome, we must provide our crops with that same foundational microbial start.

We now know we can intervene in the early stage of a plant's life with biological primers (biological application) to optimise its microbiome. This leads to measurable improvements in crop resilience, production outcomes, and, crucially, the nutritional density of the food we produce.

Priming doesn't work on its own. We need a suitable soil environment in the short term and a commitment to soil health practices in the long term to see the full benefits.

Key Findings

- **Brazil:** The Bio-Factory model proves that large-scale operations can significantly increase margins by brewing their own targeted microbes. This allows growers to move away from generic inputs toward site-specific biological priming, using locally adapted organisms to drive nutrient cycling and plant resilience.
- **USA:** A focus on endophyte integrity reveals that seed quality is a biological legacy, not just a genetic one. Sourcing seed from biologically active environments ensures the next generation inherits a robust microbiome: an internal 'starter pack' of microbes pre-programmed for resilience.
- **United Kingdom:** High-output systems prove that liquid primers, such as compost extracts, can be integrated into intensive horticulture. These extracts act as a biological 'trigger,' delivering a diverse array of microbes through industrial machinery without losing efficiency or compromising the existing soil biology.

The Economics & Health

- **Economics:** Priming allows for the unlocking of legacy soil phosphorus and atmospheric nitrogen by activating or introducing functional groups of microbes, decoupling yield from the price of fertiliser.

- **Human Health:** Linking microbially active soil to the production of nutrient-dense food highlights the opportunity to address the significant decline in food minerals since 1950.

Top Recommendations

- **For Farmers:** Adopt an 'Enhanced Colostrum' policy with targeted primers like seed treatments and in-furrow applications to ensure a robust microbiome from day one.
- **For industry:** Scale the opportunity. Farmers, industry and business co-operate to build and brew Brazil-scale biotech focusing on locally adapted microbes. This ensures biological priming is grounded in regional conditions, not off-the-shelf solutions.
- **For Australia:** Establish a national "Soil Health Framework" to provide a common language for soil health and management.

Keywords: Soil biology, priming, microbiome, resilience, soil health, seed priming

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Foreword

Growing up

I grew up on the family farm at Table Cape in North West Tasmania with my parents Paul and Bronwen and sister Meredith. I helped with our sheep, cropping and flower bulb operations.

Back to the farm

After university and some time away exploring the world outside farming, I settled back into the family farm in 2011 in my mid-20s. Being concerned that there were very few farmers to talk with about soil, I co-founded Soil First Tasmania, a farmer-led group exploring the potential for a focus on soil to enhance resilience and profit. I have hosted many groups (local, national and international) on the family farm.

Our Farm

The business is vertically integrated and is involved in general crops, wholesale bulb production, and we have significant direct sales and tourism operations.

Our customers want top quality bulbs, sustainably grown, at a decent price. We were not always able to achieve these requirements, and following a conventional system, it didn't look like things were getting any easier. I hoped turning to a biological approach would solve some problems, enable a legacy that would enhance our business and our farm environment and inspire me, our community and my children.

I became curious and frustrated that I didn't quite have the knowledge about how to successfully transition a farm over to a regenerative system. There also seemed to be a scattering of ideas but no principles or structure to take the next step past good soil practice. I sought a Nuffield Scholarship to further my interest in this field.

Table 1. Travel list - long version Appendix 4

Travel date	Location	Visits/contacts
Week 1 March 2024	Canberra	Pre CSC
March 10 - 24 2024	Brazil	Contemporary Scholars Conference (CSC)
March 24-27 2024	Argentina	Farmers and extension
April 2024	New Zealand	Farmers and Researchers
2/06/2024- 7/06/2024	Indonesia	Global Focus Program
8/06/2024- 15/06/2024	France	
16/06/2024-22/06/2024	Denmark	
23/06/2024-01/07/2024	California	
2/07/2024-9/07/2024	Chile	
16-24 March 2025	QLD NSW	Farmers, Research, Business
19 – 4 July	UK	Rothamsted, UK Vic No-Till tour and Groundswell
7 – 12 July 2025	Netherlands	Scholars, Farmers
13 -16 July 2025	France	Marie Morineau Nuffield Scholar 2024
17 -24 July 2025	USA	NY – OR, Farmers, Research, Extension

Acknowledgements

I would like to thank my sponsors, the Tasmanian Institute of Agriculture (TIA) and the J.M. Roberts Trust, and the Nuffield executive and alumni for encouraging me on the journey. I would also like to thank our farm business, Van Diemen Quality Bulbs, which did without me for so long and the family I work with, Paul, Bron and Meredith Roberts-Thomson. A special thanks to my family, Maire, Lucy, Margot and Angus, who have supported me and 'got on with it' without me. AI was used as a tool in this report.

Terminology Framework

- **Biology:** The broad "workforce" of the soil. It refers to the entire living community, from earthworms to fungi.
- **Microbiome:** The specific "ecosystem" or "community" of microorganisms (bacteria, fungi...) living in a particular niche, such as the *rhizosphere* (around the roots) or in the plant.
- **Microbes:** The individual "workers" themselves. Use this when discussing specific actions, like "microbes fixing nitrogen."
- **Primers (or Biological Priming):** The intervention or kickstart. This is the specific act of applying a trigger (like a seed treatment or compost extract) to initiate a biological process.

Objectives

- To identify successful international biological priming practices currently used on farm.
- To define the biological mechanisms that drive resilience and production.
- To evaluate the economic and ecological opportunities for Australian farmers.

Introduction

Are Australian farmers missing an opportunity?

The biological world is often vaguely understood by the average producer. While most Australian farmers recognise the value of soil health, many have experimented with cover crops or "bugs in a jug" (biological amendments) with mixed or unrecorded results. This has created a culture of curiosity tempered by scepticism.

The challenge is not just a lack of foundational knowledge, but the psychology of change. As the adage goes, "farming progress happens one funeral at a time." We are largely constructed by our environments; adopting biological models requires the courage to swim against the conventional current. This report explores how "priming" the system can bridge the gap between curiosity and profitable practice.

Why biologically priming soil matters

Healthy soils are the foundation of farming. But increasingly, we're facing challenging seasons, input prices and market whims. Biologically priming soil is the act of encouraging or manipulating the biological conditions around a seed or plant to kickstart natural processes that offer a path to resilience and production.

Economic resilience from biological/regenerative farming

- **The Opportunity:** Farming with biology by priming the system is a way to decouple yield from high-cost synthetic inputs. Instead of buying 100% of your fertility in a bag, you are "hiring" biology to unlock the fertility already bound in your soil or out of the atmosphere. This makes the farm more economically resilient to global supply chain shocks.
- **Unlock Markets:** The world is changing and people in our country and elsewhere are becoming increasingly interested in where their food comes from. By farming biologically, you can potentially unlock greater quality, prices and premium markets.
- **Farmer Wellbeing:** There is a proven link between regenerative practices and farmer wellbeing, in part from the satisfaction of leaving the land in a better state for the next generation.

What is biological priming?

In nature, a seed is never sterile. It carries millions of seed-borne endophytes (beneficial bacteria and fungi). When a seed wicks up moisture, these microbes wake up. Like colostrum to a newborn calf, this is an adaptive technique that prepares the plant for life.

Biological priming is our intervention in this process. It is a system-wide approach that can be broken into three broad practices:

1. **Growing Biology:** Creating the 'house' (the soil structure) and 'food' (liquid carbon) for biology to thrive through cover crops and rotations.
2. **Bulk Applications:** Using composts and manures to build biological diversity and soil infrastructure.
3. **Targeted Amendments:** Using precision inoculants and stimulants to trigger specific biological responses.

Quality of the food we eat – Food as Medicine

There is a growing consensus that our food is less nutritious than in the past. There are isolated alarming examples of oranges containing no vitamin C, tomatoes with less than half the nutrients of those grown in the mid-century. A 2004 study of USDA data showed up to a 38% reduction in certain nutrients since 1950 (Davis, Epp and Riordan, 2004). We now need to eat more to get the same levels of nutrients.

Dan Kittredge, the founding scientist behind the Bionutrient Food Association, explained to me that high nutrient quality best correlates with microbially active soil. By priming our biology, we are growing higher-quality food to support human health.

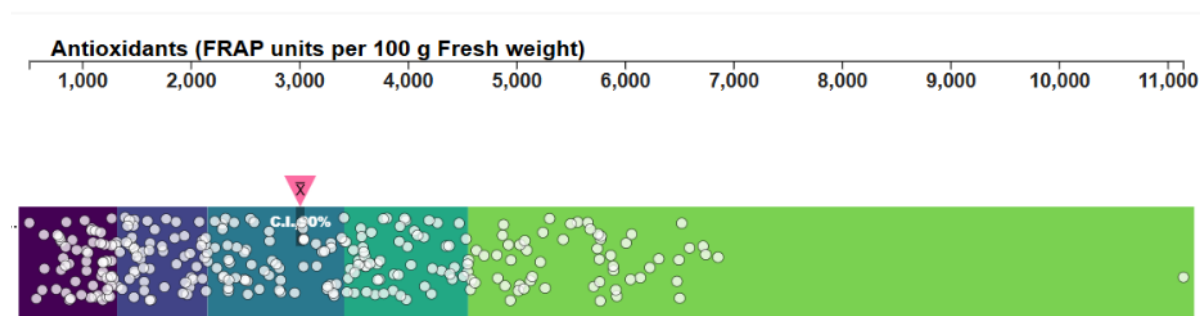


Figure 2 Antioxidant content in wheat, note the significant variability in the samples linked in part to farming practice. (Source: Bionutrient Institute, n.d.)

Building the crop - How do crops get the goods

Cropping is all about growing nutrition into plants, whether that be within a natural, an organic or a conventional system. Nutrient uptake is more than roots drinking from the soil; it is a sophisticated system divided into four main pathways.

1. Passive Delivery

Non-biological, akin to a hydroponic system. Nutrients reach the roots via:

- **Mass flow** of soluble nutrients drawn to the roots when plants use the water.
- **Diffusion:** nutrients moving from high to low areas of concentration.
- **Root interception:** Roots physically grow into new soil and intercept nutrients.

2. Root uptake mechanism from soil

Root uptake is active and selective. It regulates the nutrients crossing over into the roots through membrane proteins powered by ATP (adenosine triphosphate). ATP is the main energy currency in all living cells; it is produced through respiration and photosynthesis and is phosphorus dependent.

3. Rhizophagy Cycle – Roots eating microbes

This critical new understanding explains a sophisticated biochemical system where plants effectively farm microbes. This mechanism was first described in Australia at the University of Queensland and was advanced by Dr James White at Rutgers University, USA. The rhizophagy cycle reveals that plants attract microbes (bacteria and yeasts) to their root tips through excreting desirable food sources such as sugars and lipids (fats) and then 'eating' them, absorbing the cells inside the root tip, stripping off the cell walls using superoxides (highly reactive forms of oxygen). This releases nutrients to the plant. The nucleus of the bacteria and yeasts the plant wants to propagate are then moved out through the root hair tips in tiny explosions to reform and colonise the rhizosphere. The rhizosphere is the zone 1-2mm around the plant roots and is where most microbes in the whole bulk soil are present. There is evidence that plants will only allow the desirable species to survive and be moved all the way through the system.

This is important evidence that plants can significantly contribute to the microbial colonisation around their roots. These microbes are the symbionts that can help plants grow, by delivering nutrients or providing other services. Therefore, the microbes that colonise a root don't entirely need to overcome the native microbes in the soil to colonise a plant. This farming of microbes continues until the end of reproduction and fruit fill. After this stage the plant turns the food tap off, resulting in the microbes going dormant or becoming food for other organisms (White et al., 2018).

This is where biological priming comes into play, through introducing beneficial microbes onto the seed and/or in-furrow at planting, that can be present precisely when a root emerges to kick-start the rhizophagy cycle. This is the colostrum in or on the seed to get the crop off to a good start.



Figure 3 Rod shaped bacteria around the root tip in a cloud of exudates and the formation of root hairs.
(Courtesy of Dr J White.)

4. Soil Internet (Mycorrhizal Pathway)

These symbiotic fungi form a partnership with plants. They are not present on the seed, rather, to colonise a plant's roots, the root must meet a spore in the soil or through the application of mycorrhizal fungi to the seed. Mycorrhizal fungi's microscopic hyphae (not visible to the naked eye) can probe between soil particles and extend the reach of the root system far beyond its natural potential. Mycorrhizae supply nutrients, especially phosphorus and zinc, but also calcium, boron, copper, organic nitrogen and water, in exchange for energy from photosynthesis in the form of carbohydrates and lipids. This exchange can seem costly to plants, which can trade up to 40-50% of their liquid carbon to feed the fungus. The result in most cases is improved growth and greater resilience in times of low nutrition and water stress. The fungi are happy to colonise multiple plants and can then trade nutrition from one plant to another (Jones, 2009). In general, many agricultural soils are depleted of mycorrhizal fungi due to farming practices.



Figure 4 The halo effect of the colonisation shows just how much more soil is accessed with mycorrhizal association (Source: Smith and Read, 2008)

The plant as a community - Holobiont

Modern biology is shifting from viewing plants as isolated genetic individuals to seeing them as 'holobionts' – complex ecosystems of plant cells and microbial cells (endophytes) that work together to create a single unit.

Vertical vs. Horizontal

Dr James White described two ways plants acquire the information they need to survive.

- **Vertical Gene Transfer (VGT):** This is family inheritance. The seed carries genetic information and a foundational microbiome from the parent plant to the next generation. These microbes are deposited in and on the seed.
- **Horizontal Gene Transfer (HGT):** This is the plant's "real-time education". If a plant faces a specific stress (drought, heat, or a specific pathogen), it can recruit soil microbes that possess the genetic code to handle that stress. Through HGT, the plant can essentially "download" new survival traits from the soil microbiome. This is why varieties can often perform better over time, as the HGT can become VGT.

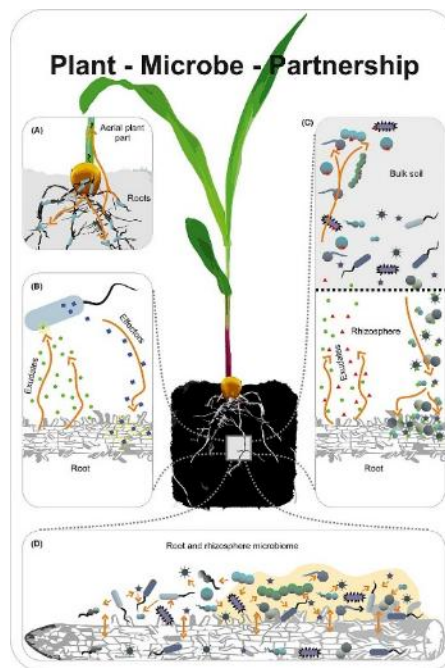


Figure 5 The plant microbiome (Source: Mitter et al., 2016)

The "Colostrum" Effect: Epigenetic Priming

The first two weeks of a seedling's life are critical. Seed-borne endophytes are an important toolkit for the newly sprouting seed. A germinating seed relies on its internal microbiome to:

1. **Trigger Root Development:** Without these microbes, many plants are slow or fail to start the rhizophagy cycle and form root hairs correctly.
2. **Activate Defence Systems:** The presence of beneficial endophytes "primes" the plant's immune system, a process known as Induced Systemic Resistance (ISR).
3. **Switch genes on:** The correct microbiome is responsible for switching the genes on in the plant that allow the plant to express its full genetic potential. This allows the plant to adapt to its specific environment in real time.

Transgenerational Memory: Plants can pass on "memories" of environmental stress (heat, drought, or nutrient deficiency) to their 'children' through epigenetic signals. A seed from a parent grown in a biologically active, stressed environment should be better "pre-programmed" for resilience than one grown in a sterile, high-input environment (Karalija et al., 2025).

Implications for Modern Plant Breeding

Historically, plant breeding has occurred in near-sterile, high-input environments, effectively assessing a "child's potential while they are in a bubble". By ignoring the horizontal element (the soil community), we may be discarding varieties that would thrive in "living soil" simply because they weren't given the "microbial education" they needed during the trial phase.

To maximise a variety's genetic potential, we must ensure the "biological community" is present at the moment of germination. This can be done by carefully selecting your seed or by biologically priming the seed with added biology to ensure that this "colostrum" is present, regardless of the history of the soil it is planted into.

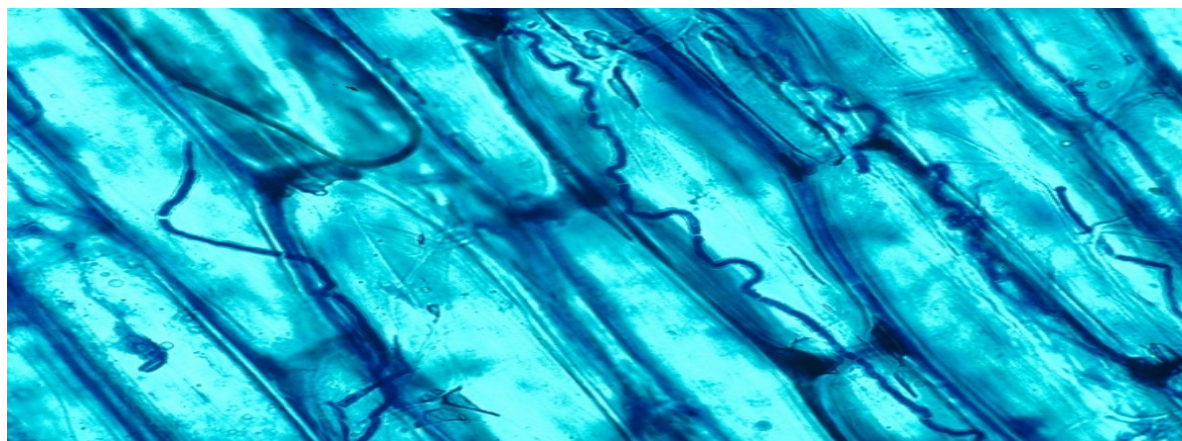


Figure 6 Blue-stained serpentine *Neotyphodium coenophialum* mycelia inhabiting the intercellular spaces of tall fescue leaf sheath tissue (Source: Hill, 2006)

Understanding these biological pathways allows us to move from black box soil health to intentional biological priming. However, before we can drive the system, we must ensure the soil is fit for purpose.

Before you start – Address these soil constraints

It is important that we understand some chemical and physical properties before we start trying to improve the biological system. Biology needs a 'house', a place to live, and 'food' to eat:

- **Compaction.** Biology needs to breathe. Compacted soil lacks the oxygen required to support beneficial aerobic life and roots.
- **Harmful chemistry.** High salts either from the parent material, water table or applied fertilisers like muriate of potash can severely affect beneficial biology. You can't build biology on a foundation of salt.
- **Flocculation and Dispersion.** If the soil's calcium to magnesium ratio is significantly out, the soil can 'seal' itself, choking biology of air and water. Biology works best in crumbly well aggregated soil.
- **Nutrients, and co-factors.** Biology needs a range of nutrients and water to grow. Biology is 70-85% water. There is significant crossover with carbon (50% of dry weight), oxygen, hydrogen, nitrogen, phosphorus, sulphur and others. There are other minerals that are essential to catalyse reactions called co-factors. Without each of these, biological activity stalls. It may be necessary to apply trace amounts in your system.
 - **Magnesium (Mg):** Essential for microbial DNA replication and stabilises cell walls.
 - **Calcium (Ca):** Vital for the structural integrity of fungal hyphae.
 - **Cobalt (Co):** The essential core of Vitamin B12. Without cobalt, nitrogen-fixing bacteria (like *Rhizobium*) cannot function.
 - **Molybdenum (Mo):** The key component of the *nitrogenase* enzyme. Without "Moly," microbes cannot convert atmospheric nitrogen into a form the plant can use.
 - **Manganese (Mn), Iron (Fe) and Zinc (Zn):** Essential for the enzymes that protect biology from "oxidative stress" (environmental harshness).
 - **Other minerals:** There are many other trace minerals that can contribute to biological activity in the soil; however, they are less critical and difficult to isolate.

Australian Soils

Our soils are ancient and weathered. Because many are inherently nutrient-poor, we have a massive opportunity to use biological priming to maximise the efficiency of every unit of nutrition we apply.

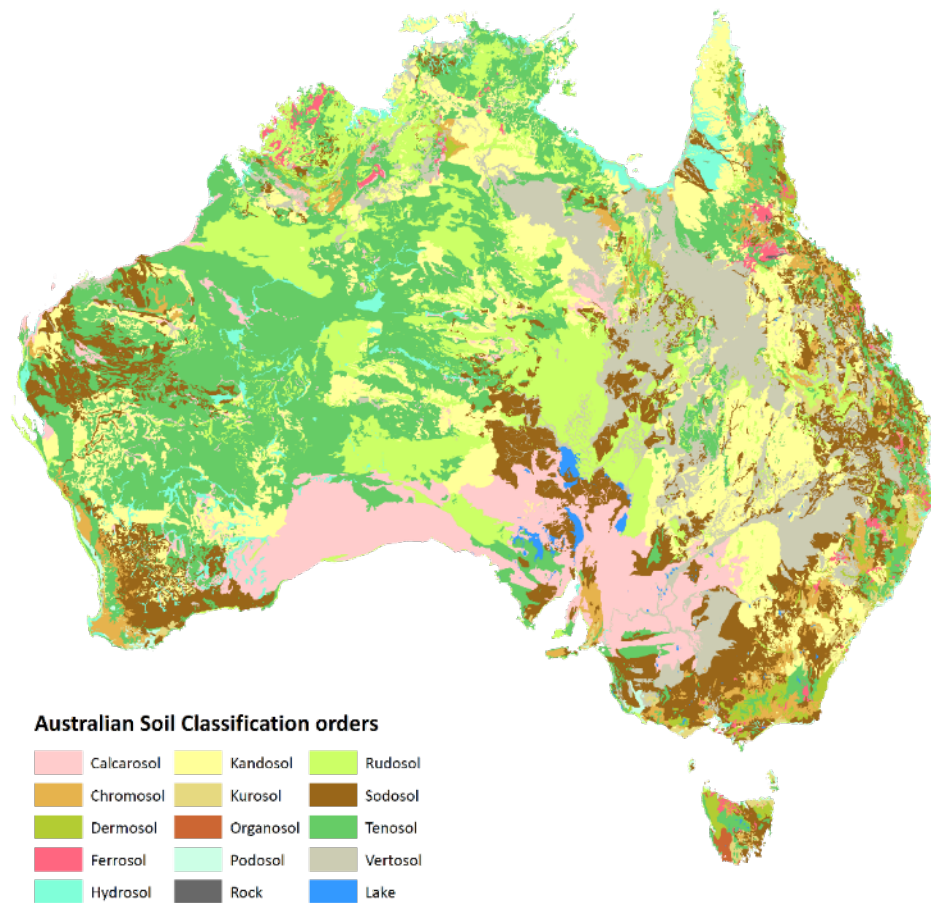


Figure 7 The diversity of Australian soil types (Source: Metcalfe and Bui, 2021)

Growing the Soil Biology

Growing a biological community is a foundational, long-term, and systemic approach to nurturing your land. It's about creating a suitable environment and providing the continuous food and shelter that diverse microbial communities need to flourish naturally. These communities are a legacy of your management, crops, and native soil environment. This is the most traditional way to achieve sustainable results. While priming may provide a kick start, these practices sustain the change.

The Framework: Soil Health vs. Conservation Agriculture

To manage soil effectively, we need a shared language. While Australia lacks a formal national directive, we can adapt the two leading global frameworks: Soil Health Principles and Conservation Agriculture. These principles have stuck around and have been transplanted all over the world. There is significant overlap, but the two sets of principles sometimes differ in their emphasis. They are:

Theme / Principle	USA – Soil Health Principles (NRCS)	Europe – Conservation Agriculture (CA)
1. Minimise soil disturbance	Reduce physical, chemical and biological disturbance; limit tillage to protect aggregates, soil structure, and biology. Encourages no-till or reduced-till where possible	Core Principle: No-till/minimal tillage is a <i>core requirement</i> of Conservation Agriculture (CA). Soil disturbance must be below a strict threshold (often <25% soil disturbed). Deep tillage is largely incompatible with CA certification.
2. Maximise soil cover (residue retention)	Keep soil covered year-round with plant residues or living plants to reduce erosion, buffer temperatures, and feed microbes. Flexible in approach.	Core Principle: Retention of at least 30% surface cover is a <i>formal CA criterion</i> . Stubble burning is discouraged or prohibited. Soil cover is part of compliance frameworks for EU farm programs.
3. Maximise living roots	Encourage living plants for as many months as possible through cover crops, multi-species rotations and perennial phases to support microbial activity. Considered the most important rule by many.	Promoted indirectly through crop rotation and cover crops, but not always mandatory. The EU has seasonal climatic constraints; living roots emphasis varies by region. Increasingly encouraged through eco-schemes.
4. Increase biodiversity	Integrate diverse species through rotations, cover crop mixes, intercropping, and inclusion of perennials. High emphasis on functional diversity to stabilise the soil ecosystem.	Core Principle: Biodiversity primarily expressed through diverse crop rotations (often 3–4 species minimum). Intercropping is allowed but less codified. Focus is on pest/disease reduction and resilience.
5. Integrate livestock	Animal integration (grazing cover crops, managed grazing systems) is encouraged as a biological	Not a core part of CA definition. Some EU regions integrate livestock, but many CA systems are arable-only and livestock is

	accelerator, but optional based on farm type.	considered an “optional enhancement,” rather than a principal pillar.
6. Context and adaptation	NRCS emphasises that principles must be applied based on local climate, soils, economic realities and farmer goals. Flexible and farmer led.	CA has more formal, standardised definitions across Europe (0 tillage, permanent cover, rotations). Less open-ended; systems are more tightly defined for certification and subsidies.
7. Aim / Core Philosophy	Improve biological function of soil: structure, infiltration, nutrient cycling, and long-term productivity by mimicking natural ecosystems.	Reduce erosion, improve water/soil conservation, increase efficiency, and stabilise yields while reducing external inputs. Strong focus on environmental and policy objectives.
8. Policy + regulatory environment	Voluntary framework. Adoption driven by farmers, NGOs, market incentives, and local programs.	Strongly shaped by CAP (EU Common Agricultural Policy) eco-schemes and compliance standards. Adoption often tied to subsidies and environmental performance.
9. Innovation + technology frame	Emphasises adaptive management, farmer-led experimentation, local soil testing, biological inputs, and practical resilience tools.	Emphasises long-term compliance with CA definitions, mechanisation for direct drilling, and integration with environmental monitoring/reporting.
10. Cultural adoption style	Rooted in regenerative agriculture movement; bottom-up with significant variation by region and crop type.	More top-down adoption supported by government/industry; more uniform definitions required for policy alignment.

Australian Opportunity

By adopting these principles, Australian farmers can create the infrastructure (pore space and carbon) required for biological priming to succeed. You cannot expect microbes to do the heavy lifting in a cropping system if they don't have a home.

Australia would benefit significantly from an agreed set of principles that are taught in universities, used in extension and on farms alike. Without this can we really have high quality conversations?

Cover Crops – The living soil primer

Do not underestimate the value of a good cover crop to the soil. It is a biological priming event. The living roots can build significant microbial populations, unlock nutrients and create root channels that will support your next crop.

- **The Variable Rate effect.** Mixing species in cover crops works because of different soil niches in your paddock. Compaction, nutrition, moisture, low or excess fertility.... Each cover crop species has a niche in the environment, and one will be ‘selected’ to

grow. All plants prefer and encourage a specific microbiome; by mixing seed you can achieve a broad range.

- **Quorum Sensing.** This name describes the event where microbes behave differently when there are a significant number present. The microbes can make chemical 'calls' to see who is around. When the calls get strong enough through multiplication, they have reached a quorum, they now can have a 'meeting' that allows them to start providing functions they could not do on their own. This is why microbes appear to do nothing and then all at once transform a crop. A pathogen can also reach a critical mass (quorum) and elicit disease symptoms. The benefit of mixed species planting is that, with a diverse microbiome, it is unlikely any one pathogen will reach quorum (Singh et al., 2024).
- **They just grow better together.** Crops grow more biomass when grown together. This could be explained through nutritional reasons, such as access to minerals through rhizosheath sharing between species. It could also be that there are structural reasons, like a vetch climbing an oat to access more sunlight. There are also biological reasons, including sharing of biology across species. This seems to be significantly pronounced when opting for a low input model.

Managing cover crops in a system

A farmer just starting to grow cover crops will likely arrive at some conundrums at some point; when to terminate, how to drill through the cover biomass, will it break down in time to release nutrients, will the soil be too wet or too dry due to the cover.... The one factor that is critical to understand with cover crops is the Carbon to Nitrogen ratio of the cover crop. If you want a soft cover that breaks down quickly, get a low C:N ratio; if you want a persistent cover, focus on a high C:N ratio. These ratios will change at different growth stages of the crop. Mature crops will generally have a higher C:N ratio. It is also wise to find a mentor in your area, with local experience to impart. Some businesses who sell seed provide a lot of information alongside the seed.

Green Cover – Case Study

I visited Green Cover, owned and operated by the Berns family in Nebraska. This business specialises in cover crop seeds and is now branching out into seed crops. They are currently responsible for covering one million acres of land with cover crops and crops. Their business focuses on several different soil health and biological priming approaches. These approaches stack together to create value for the end user and a niche for their business. They are one of the few companies I know of that are actively focusing on endophytes (seed borne microorganisms) and gene expression in their seed. They are trying to source all their seed from local biologically active soils, for competitive advantage in quality. By growing in biologically active soils, they can improve the gene expression of the plants, making the plants more resilient, and healthier. This leads to an enhanced soil microbiome that can lead to increased beneficial endophytes in the next generation.

Green Cover ensures that the seed planted has a diverse but tailored biological environment full of dormant microbes and stimulants on the seed at planting. The seed is then grown out (multiplied) on other farms and brought back. The other farms are aligned with the mission of Green Cover and are supplied with biologically primed seed. The business is structured to

help farmers understand this process and the value it provides to them. By ensuring that education is central to their business model, Keith and Brian Berns have achieved significant gains for biological farming.

In traditional farming, the standard mode for selecting quality seeds is by isolating the biggest and heaviest. This is successful because they are fully developed and likely have the highest nutrient integrity, internal energy and microbiome of that batch.

As discussed before, almost all seeds have some endophytes, and all soil has microbial life. Using biological methods, we have the opportunity to enhance it.

Aside from biologically primed seed, Green Cover are leaders in mixed cover crops. They have developed a cover crop calculator app on their website called 'Smart Mix'. This allows the farmer to choose cover crops based on their desired outcomes and considers climate by zip code, irrigation, and growing dates. This allows the grower to target certain goals and (in my experience) teach them of the options that cover crops can achieve. An example may be that someone is focused on nitrogen fixation as a cover crop goal, but with a few tweaks that the calculator recommends you may end up with a mix that is suitable for nutrient cycling and nematode control as well. The calculator is free to use. You will need a zip code that has similar seasons to your own to get the best out of it.

Access the crop calculator here:

www.greencover.com

<https://smartmix.greencoverseed.com/>

Intercropping - Mixed Species Crops, opportunities and variants

The current understanding of conventional broadscale cropping is as a monoculture. In the future, polyculture systems will likely be more prevalent to take advantage of the biological synergies. There can be a significant leap in growing two or more species at one time.

Relay cropping

Relay cropping refers to the process of sowing the next crop into the first. A classic example is winter wheat planted in autumn then sowing soybeans into it in spring and harvesting the wheat before the soybeans. This can equate to a 120+% increase in total volume of grain after harvest. These crops often use beneficial biological stimulation to encourage the system.



Figure 8 Jason Mrauk Indiana is a leader in a community of farmers learning how to relay crop. Inter-seeding soybeans into wheat around tillering. The combine pushed the soybeans down slightly in the rows while the wheat is harvested. (Source: X @Jasonmaru)

Mixed Species Cash Cropping

There are many markets and opportunities to blend crops together for co-benefits and for them to be harvested together. It is very easy to grow a mixed species grain crop. The issues are generally around weed control and markets. Combinations of crops that seem to be gaining traction internationally:

1. Beans (faba) and oats – 'Boats' are becoming common in the UK and are also working on our farm. Dramatic reduction in disease in beans and increase in total yield and very low input.
2. Chickpeas and linseed (flax) – Canada. Dramatic reduction in disease and fungicide applications in chickpeas
3. Mixed Species Grain/Legume – France. Cut for silage or take for grain.



Figure 9 Mixed species intercrop near Sées in northern France. Counting the species in a mixed species grain crop in Normandy, France (Source: Author)

Companion Planting and Living Mulches

This is an accepted practice amongst organic growers in cropping and in horticulture, simply choose the species that will complement your cash crop. In England I observed the use of a

prostrate clover called 'Rivendell' grown with wheat and rye corn. It was used due to its growth habits, because a late harvest could see other white clovers grow up through the canopy and further complicate a late harvest. Other methods such as 'pasture cropping'/'no-kill cropping' in Australia have gained traction.

The Feedback Loop - Plants Feed Soil, Soil Feeds Plants

We hear 'to grow a healthy plant we need to have healthy soil'. But to grow healthy soil we need healthy plants; the chicken and the egg situation. There is no magic in biology; it requires energy. The 'cheapest' energy is from a plant root exudate. A healthy plant will contribute much more energy to its microbiome than a weak plant. This provides an opportunity for farmers to use foliar feeding to bypass a nutrient deficiency in compromised soil. Appropriate foliar feeding encourages photosynthesis that will kick the root exudates along, where the plant can hire more microbes that will in turn feed the plant.

Bulk Applications

Bulk application provides direct inoculation and broad-scale nutrient provision to accelerate the establishment or revitalisation of microbial communities. It's about giving the existing soil biology a significant "kick-start" or a substantial boost of diverse life and microbe friendly nutrients.

Through the medium and short term this application method has been considered a primary way to improve fertility. Whether it be from compost, 'night soil' (human manure) from cities, animal bedding and just walking livestock on to land for them to feed and defecate, this transfer of nutrients is well intuited. It is also the case to some extent that the agricultural community understands the notion that you can transfer microbes with manure, compost and other biological fertilisers. It is less 'believed' that the application of microbial foods and stimulants can change the trajectory of a crop. It may be even less believed that introducing microbes to the whole paddock through a sprayer may tweak the soil biome and enhance a crop.

Types of bulk applications

- Solid applications like bulk compost, prills/pellets, microbially friendly fertiliser.
- Boom spray, stubble digester applications, co-factor nutrients and other bio-stimulants
- Manure spreading, manure injection

Primary Composting Methods

There are many types of compost and they all have merit. Compost is a carbon-based fertiliser that harbours microorganisms that can inoculate soil and improve its structure, cation exchange capacity and water holding capacity. See the table below for different types of compost.

Method	Microbial Profile C:N Ratio	Key Priming Benefit	Ways of Applying	Logistical and DIY issues
Aerobic (Windrow)	Bacterial dominant; high species turnover due to heat. C:N Ratio 25-30:1	Rapidly stabilises raw organic matter; high volume "infrastructure" building.	Bulk spreading (2–20 t/ha); sieved for dry seed coating, liquid extracts.	Requires frequent turning and moisture monitoring; potential for N-loss to atmosphere.
Vermicompost (Worm Castings)	Highly diverse; rich in growth promoting bacteria. C:N Ratio 15-20:1	Highest concentration of plant growth hormones (auxins/cytokinins) and "chitin-eaters" for pest resistance.	Seed treatment (2kg/t with sticker), liquid extracts; in furrow at planting.	Worms require moisture control; hard to scale for bulk broad-acre use.
Johnson-Su (Static Fungal)	Highly diverse and fungal dominant. C:N ratio >50:1	Restores the fungal to bacterial ratio; triggers the	Primarily liquid extract in-furrow	Long lead time (12+ months); requires initial

		Rhizophagy Cycle in depleted soils. Benefits of vermicompost	seed treatment or transplant drench. 2kg/ton or ha	labour-intensive setup
Bokashi (Fermented)	Anaerobic/Facultative; high in Lactic Acid Bacteria (LAB) and Yeasts.	"Pickles" nutrients to prevent leaching. Microbial metabolites provide signals and chelated minerals, and a rapid energy "kick" to soil bacteria.	Direct soil incorporation (must wait 14 days to plant); leachate used as seed soak.	Requires airtight environment; finished product is "acidic" and needs soil buffering before planting.



Figure 10 This small-scale aerobic compost operation was at Lockerley Estate & Preston Farms UK. This high-quality compost of ample quantity to be made into a compost extract for their wheat, barley, faba beans, and oil seed rape over 800ha at just 1.5kg of compost (Source: Author)



Figure 11 A large scale vermicomposting plant in California. This unusual plant's main role was to filter washings from the vineyard. The outcome was a significant reduction in soluble solids and nutrients. They were captured in the wood chip substrate and cons (Source:Author)



Figure 12 Stuart Jakeman arable farming in the UK using Bokashi extract at 1:100 dilution on seed with humic and fulvic substances. Impressive rhizosheath (aka dreadlocks) indicating a thriving biological community developing on the new roots. (Source: Author)



Figure 13 A classic home compost rotting in the yard. The uncontrolled carbon to nitrogen ratio and oxygen means that this has turned rotting that further collapses and reduces oxygen. This is not a safe product to use on the farm. (Source: Author)



Figure 14 Johnson Su Compost being made at Kalfresh in the Fassifern Valley Queensland Australia. Rob Hinrichsen has been trailing the extract on vegetable crops. (Source: Author)

G's Fresh – Case Study

G's Fresh is an impressive family-owned company, established in 1952 producing lettuce, celery and other fresh vegetables. It operates over 14,000 ha of land, through five countries in Europe and is expanding to the USA and Senegal, producing primarily for the UK market and it turns over £720 million per annum (AU\$1.3 billion).

G's Fresh is heavily exposed to the realities of European and worldwide agreements to mitigate climate change through greenhouse gas emission mitigation. The farm I visited on peat soils was showing oxidation of the peat land at rates that had become a business risk. The business was also experiencing crop quality issues that were resulting in significant packable crop losses. This was born out of soil health issues on land that had been cropped for decades. Essentially, they needed to change. They started by making adjustments in soil health:

- **Minimise Soil Disturbance.** 75% less ploughing. 95% less aggressive deep tillage, 100% increase in low disturbance tillage.
- **Maximise Soil Cover (Armour the Soil):** Now cover cropping almost all of the 14,000 ha
- **Maximise Biodiversity:** Moving from 4 plant types over 3 years to 14 and aiming for 21 (extra plants in cover crops).
- **Keep Living Roots Year-Round:** With the further roll out of cover crops they have increased living plant cover from 61% to 81% of the year.
- **Integrate Livestock:** Reintroduced 4000 sheep to graze cover crops and cash crop residue.

In their context on their farm in The Fens, the adjustments they made have seen the changes listed above.

This had some success in the new rotations, but it wasn't until they attempted to include all the principles together in the rotation that they started seeing real results. By focusing on the system, the soil and biological life started to change and began recovering from the intensive farming. G's Fresh were interested in the addition of compost but to be realistic over their 4000ha it had to be a liquid application. Around this time, they met Dr David Johnson and his work on highly fungal compost extracts.

Johnson Su Compost Extract at G's

This simple and intuitive system for making fungally dominant worm compost was attempted at G's Fresh to try and boost the beneficial species and outcompete the pathogens that were preying on their leafy greens.

This relatively simple system has demonstrated incredible results. I observed this system being used across at least ten farms over three continents, on crops ranging from lettuce to corn to tree crops. I observed positive results across environments and crop types.

Dr David Johnson and co-creator Hui-Chun Su Johnson developed a methodology and equipment to safely create a three-in-one compost. It is a thermophilic (hot), vermi (worm) and static (no turn) compost. This system:

- Is free of pest and weed seeds.
- Is fungal dominant and highly diverse. Fungal dominant compost is harder to achieve in turned compost.
- Maintains aerobic conditions while remaining static (is undisturbed after making).
- Requires a long process (over 12 months). This can be a sticking point for many growers.
- Includes composting worms after the heat phase.
- Has intense setup but only requires monitoring after that.

This compost is used in farm systems via application of a compost extract across the paddocks – the finished JS compost is washed in water to extract the microbes and their metabolites from the compost.

We might expect to see the best results from applications of this compost in soil that has a low population or diversity of fungi.

By adding Johnson Su compost extract to their system, G's hoped to reintroduce beneficial fungi as well as flood the soil with beneficial microbes that will outcompete the pathogens. At first the extract was applied to the soil at planting and to seeds for their cover crops. Recently it has started to be applied to the transplant plugs of lettuce and celery. This was a surprise to them as their lettuce plugs are grown in highly concentrated and conventional ways including a stringent fungicide program. It is suspected that this addition boosted the rhizophagy cycle, colonising the roots.

They have seen marked increases in:

- **Marketable yield** – increase of lettuce heads making it through.
- **Shelf life** – extended by several days.
- **Return** – More profit for the company.



Figure 15 The G's Fresh final pass cultivator has several functions. It applies JS extract before the tines to be stirred into the soil, it lays liquid fertiliser below where the lettuce will be and then sprays a pre-emergent herbicide over the soil pre-planting. (Source: Author)

Livestock and Manures – Mobile Priming Systems

To a modern cropping farmer, livestock are often seen as a complication, but in a biological system they can be used as a delivery mechanism for soil health:

Biological inoculation: The Haggertys in Western Australia use sheep from their home farm to inoculate new land. Fresh manure is a biological fertiliser and is seen as an essential and cost-effective way to prime the land for cropping.

Strategic Nutrient placement: Bale grazing is a form of strategic nutrient placement that refers to placing bales on damaged soils (such as on hill tops) to concentrate carbon and biology in those places. I observed this practice being used successfully at Tim May's farm, Kingsclere Estates, in the UK.

Ruminant enhanced spreading: Livestock can be used to prime and spread amendments. For example, feeding livestock on biochar or clover seed allows the inputs (manure) to be biologically charged before they are deposited. These are then further moved by dung beetles and worms.

Manures applied from a pit: When evenly spread, manures can provide a rapid kick start for microbial activity but can be high in ammonia and salts that hurt the microbes. When buffered with carbon (like biochar) or diluted, they can be a helpful addition to indirectly prime the soil but are better considered as fertiliser.

Bio-stimulants

Bio-stimulants are a useful tool that signal and stimulate plants, applied microbes and life already in the soil. They can be used in many areas of biological priming, both in growing crops, and as a whole paddock bulk amendment. They can also be used in a targeted amendment package and be paired with either microbes and/or nutrients. Common options include:

- **Humic and fulvic acid:** This complex, typically liquid, carbon source provides signalling, chelation of minerals and a complex food source for microbial life. *Typical application 2- 5L/ha*
- **Molasses:** A simple carbon source primarily consumed by bacteria and yeasts. Cheap and effective, but not to be overused. *Typical application 1 - 10L/ha*
- **Fish emulsion and hydrolysate:** Provides amino acids, peptides, fats and some nutrients. Supports fungi and can also stimulate plant growth. *Typical application 1- 10L/ha*
- **Seaweed extract:** Provides beneficial hormones and root stimulation. Improves stress tolerance in crops. Feeds and conditions soil biology. *Typical application 1- 5L/ha*
- **Co-factors:** Small amounts of nutrients and traces to feed and support microbial functions.

Typically, a bio-stimulant package wouldn't exceed 10L/ha because of cost and due to the small amounts required for stimulation. Bio-stimulants are tools to stimulate biology; if there is a weak biological foundation the results are likely to be short lived.

How to do it

How to make extracts and biological inputs on farm is a huge topic and there are some excellent resources. Two recommended resources are:

soilsforlife.org.au/farming-practice-guide-biological-inputs-and-fertilisers/

Facebook page: Farm Made Biofertz; <https://www.facebook.com/groups/5515612835228780>

More information is in Appendix 3.

Evaluation: 'What have you got?'

A farmer might buy or make their own compost or other biological amendments on farm, to biologically prime the soil. Before applying they must test if they are safe and effective.

Farm Tests

- **The Cress Test:** Scientifically backed and highly effective means of testing for phytotoxicity on any input. Cress is highly susceptible to toxins. The test involves growing cress seed in a 50/50 mix of soil and amendment to see whether the seedlings die or thrive. The test includes 2 parts: open air growing and closed bag that detects lower levels of toxins. The same test can be used for liquid amendments with care. (Fuchs and Weidmann, 2018)
- **The Fist Test and Sniff Test:** Compost test that checks for moisture, and odour (anaerobic = smelly and toxic). Incredibly simple and learnable. Good compost should smell earthy not like ammonia or rot. (Michel and Fuchs, 2020)
- **Solvita CO₂ + Ammonia:** A simple test that measures CO₂ respiration (indicating biological activity) and ammonia levels.

Lab Tests

- **DNA sequencing:** Identifies the species in the compost and their concentrations.
- **PLFA:** Phospholipid Fatty Acids are the fatty parts of microbial cells. This test measures the unique signatures of different groups. It gives an overview of microbial quantity and quality.
- **Haney Test:** Measures soil respiration (how much activity) and how much water-soluble carbon (food) is present.
- **Microscopy:** Looking at and identifying species groups from the sample by eye. Can be done on farm with training. (Elaine Ingham, Soil Food Web).



Figure 16 The Cress Test in action, evaluating amendments for seed safety (Source: Author)

Targeted Amendments – Precision biology

This category represents precision interventions designed to support the plant-microbe relationship at critical growth stages, giving the crop a competitive advantage from the very beginning.

Single Strain Biology – Biology for a job

This is a controversial area that has competing philosophies. One is that biological agriculture can be seen as an extension of modern agriculture where we can apply the right microbe, at the right rate, at the right time, in the right place to solve problems much like fertiliser or chemicals. The other philosophy is that we nurture and protect our ecosystem and apply a broad spectrum of microbes and let the plants dictate which ones they will support. This philosophy suggests that it can be arrogant to assume we know exactly what is needed in a complex ecosystem. New advances in DNA sequencing are starting to unlock these interactions and processes. Regardless of the philosophy, single strain biological products are popular choices and there is evidence to support their use.

Some popular biological amendments are: (for more detail please see Appendix 2)

Category	Key Species	Role
Nitrogen Fixers	<i>Rhizobium</i> , <i>Azospirillum</i> , <i>Azotobacter</i>	Converting atmospheric N into plant-available forms.
Phosphorus Miners	<i>Bacillus subtilis</i> , <i>Pseudomonas fluorescens</i>	Solubilising "locked" soil phosphorus and scavenging iron.
Biocontrol (Defence)	<i>Trichoderma</i> , <i>Beauveria bassiana</i> , <i>Bacillus amyloliquefaciens</i>	Warding off soil-borne pathogens and parasitising insect pests.
Growth Stimulators	<i>Bacillus pumilus</i> , <i>Mycorrhizae</i>	Triggering root branching and improving water/stress tolerance.

Brands like Bayer's Serenade Prime are being widely used for a variety of applications including potato crops in Tasmania. I saw it being used at a biodynamic farm in the Netherlands that grows berries. They had some wet soils and were using it to ward off Phytophthora (a disease-causing, fungus-like root organism).

Brazil Case Studies

Brazil's agricultural landscape is unique due to its vast scale, diverse land types, and large-scale commodity production (soy, corn, cotton, sugarcane, etc.). This context has heavily influenced its biological amendment culture, leading to what can be described as a "product-

centric" approach. Its vast scale, uniform no-till equipment, and warm, humid climate have created an ideal place for biological adoption. Unlike other regions where biology is seen as alternative, in Brazil, it is a mainstream economic driver.

Beyond Rhizobium, a short history of Brazilian Biocontrol

The foundation of Brazil's biological culture was the widespread adoption of *Rhizobium* inoculants in the 1960s. By proving that biology could replace synthetic nitrogen in soybeans, the government (via **Embrapa**) and private industry believed that biology could help and actively engaged in research in this field.

- **The Evolution:** In 2014, the introduction of co-inoculation with *Azospirillum* (an associative nitrogen fixer) saw another leap in yields, cementing the idea that biological "stacking" works.
- **The "Product-Centric" Culture:** This initial success led to a "product-centric" approach. Brazilian farmers aren't necessarily trying to be "organic" or "regenerative"; they are focused on yield and margin. They view biologicals as high-performance tools that can be integrated into conventional spray programs to lower costs and increase efficiency.

The "Silver Bullet" Risk

While effective, this approach can lead to a "silver biological bullet" mentality, looking for a single microbe to solve a single pest problem. However, the sheer scale of these farms means that even a small reduction in pesticide use per hectare equates to a massive increase in total farm margin.

Government-Backed Innovation

Institutions like Embrapa have been crucial in isolating native microbial strains adapted to local conditions. This "local focus" ensures that the microbes can survive the high UV and temperatures of the tropics. This may be a lesson for Australia in the importance of mining our own native biome.

Big Brazilian farms grow their own

I was fortunate to meet the heads of two very large farms in Brazil, Aurélio Pavinato the CEO of SLC Group and Guilherme Scheffer of Scheffer, farming over 500,000 ha and 250,000 ha respectively. At this scale, buying biological inputs provides the opportunity to lower input costs. Both farming operations had installed biological factories to produce many of the accepted and established microorganisms that were being used as stimulants and biocontrol agents, further lowering costs.

SLC Group – Microbials in bigger than big farms.

Their typical Brazilian approach was to use existing research to apply known biocontrol agents to their crops and soil, much of which was made on farm in bioreactors. The farm sheds

seemed to resemble a modern brewery or distillery more than a typical shed. They produce a biological workforce of over 20 species of fungi and bacteria (See Appendix 1).



Figure 17 Top: an SLC Group farm; dinner with the CEO Aurélio Pavinato and a map of farm locations in Brazil (Source: Author)

Scheffer – Exploring the biological opportunities

Scheffer is a family-controlled agribusiness farming on 250,000 ha. Their journey in microbials began with "Indigenous Microorganisms" (IMO) but evolved into a sophisticated program of isolating native microbes. They have isolated over 500 unique strains, partnering with multinationals to license successful discoveries while using the technology to transition toward regenerative commodity markets. The resultant reduction in chemical inputs has allowed them to start looking at regenerative markets for their commodity crops. Their next endeavour was to purchase the technology from Nova Crop Control in the Netherlands and start up South America's first sap analysis laboratory to further their opportunities in realised crop health.



Figure 18 The facility used to brew their biological inputs (Source: Author)

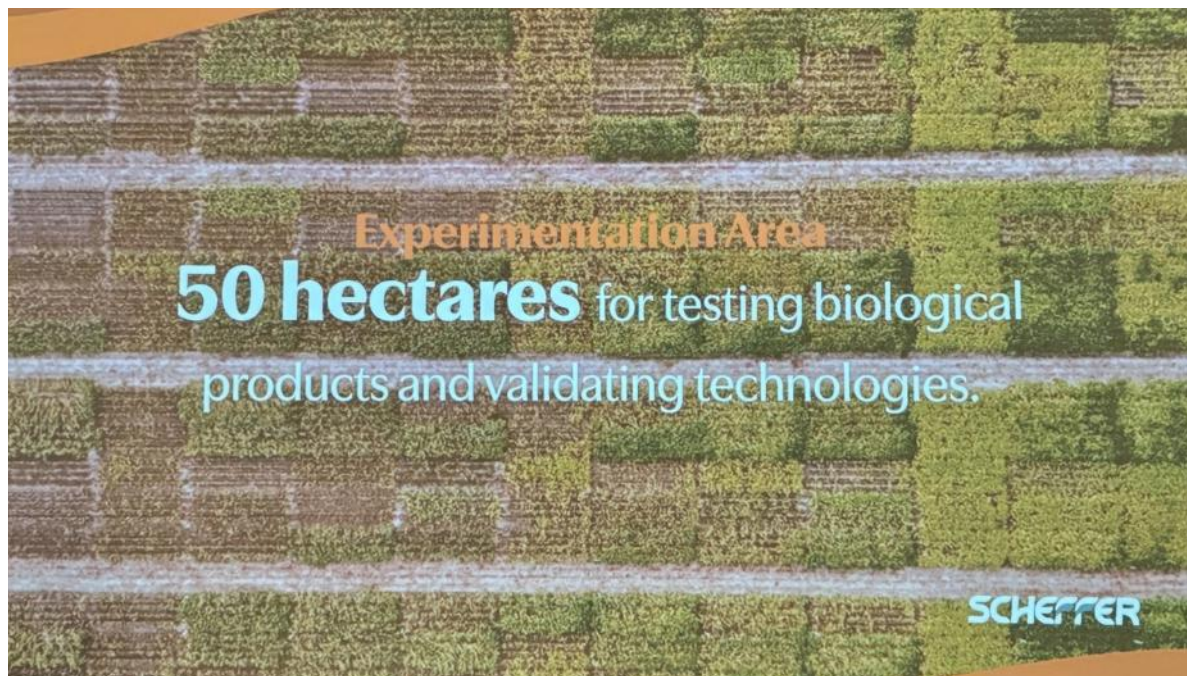


Figure 19 Validation of biological inputs on corn and soy at Scheffer farm in Brazil (Source: Scheffer)

Mining the Native Biome: Chile and Australia

It may be that the most resilient "primers" are found in our own backyards.

University of La Frontera (Chile): Researchers are isolating microbes from extreme volcanic regions, finding they possess superior survival rates in commercial cropping.

The "Home Field" Advantage: In reforestation trials, introducing a tree's native biology (soil/litter from a healthy parent) increased germination by 150% (Gerrits et al., 2023). This mirrors the work of Loam Bio in Australia, which screens native fungi to build soil carbon.

Calendar of priming operations - Nebraska

Brian and Jenny Brhel are farming near Lincoln, Nebraska. They are implementing a farm plan established by Jim Williams of Herrick, South Dakota. Brian and Jenny take a scientific approach to applying biology to their grain crops, prioritising both type and timing of biological inputs. They are using compost extracts up to five times a year at approx. 1kg compost/ha. To this they add an extraction of seed endophytes (grow the seed and wash them off), mycorrhizal fungi and nitrogen fixing bacteria.



Figure 20 Brian and Jenny
(Source: Author)

Their priming calendar:

Timing	Stage	How	Reason
Fall/Autumn	Post harvest	Spray	To help break down crop residue and hold the nutrients in a biological form, ready for next season.
Winter/Spring	Pre-planting	Auger - liquid	To charge up the seed with biological signals to germinate
Spring	Planting	Liquid injects	To apply live biology and food to intercept the root system
Early Summer	After herbicide, early in crop life	Sprayer	To mitigate the effect of the herbicide
Summer	Flowering / as late as practical	Sprayer	To influence and encourage endophyte transmission in the seed.

The most important applications were in the fall (autumn) post-harvest, and application on seed or in furrow on planting day.

The Path Forward – Risks, Economics, and Ethics

What to avoid

Sometimes it is simpler to state what not to do when the goal is to support a thriving microbial community within agriculture. There are many things that can set soils back, with major factors including:

Practice to Avoid	The Biological Cost	The Regenerative Alternative
Muriate of Potash (KCl)	High salt/chloride kills soil life and tightens soil.	Sulphate of Potash (SOP)
Prophylactic Fungicides	Blocks the connection between plant and fungi.	Biological seed dressings, apply nutrition and biology in place of fungicide
Bare Fallow	Starves the microbiome and bakes the soil surface.	Cover Crops / Living Roots or brown mulch

Economic resilience of biological farming

Conventional agriculture is tethered to the price of N, P, K and trace elements. Biologically priming the soil unlocks legacy P, atmospheric N and trace elements. Biological priming allows the farmer to not just grow a crop but also foster a biological supply chain for the future.

Who will benefit from Biological Priming

- **The Farmers** – Reduced input costs, improved soil resilience, and a greater sense of "wellbeing" from looking after the land.
- **The Eaters** – Improved nutrient density. As noted by Dan Kittredge (Bionutrient Food Association), microbially active soil strongly correlates with high-quality, nutritious food.
- **The Environment** – Reduction in pesticide runoff and increased biodiversity.

The Challenge: This shift is socially "tricky." It challenges the traditional business models of agrichemical sellers and requires a move away from reductionist research that ignores biological interactions.

Conclusions

Modern agriculture is slowly moving from a chemistry dominant paradigm to a biology/chemistry focused paradigm. In recent history, we have used and thought of the soil as a container for synthetic inputs. My research shows that, by using biological priming as a strategic intervention, we can re-establish or enhance a symbiotic microbiome that plants evolved with. When we apply the right microbes at the right time, we unlock a level of resistance and nutrient integrity that synthetic inputs can't replicate. The future of Australian agriculture is not more synthetic inputs but an increased understanding and management of our biology.

As Dr Suzie Haryanti Husain noted, 'soil biology doesn't always need help surviving; it needs help *recovering*'. Most modern fields are biologically burned out, compacted and oxygen-starved. By providing the "colostrum" at the start and the "house and food" throughout the season, we can start to recover and build these soils.

The work of Dr James White and operations like G's Fresh and SLC Group prove that the plant is an active manager of its own microbiome. By understanding these natural systems like the rhizophagy cycle, mycorrhizal associations and the role of endophytes, we can move beyond a 'black box' understanding of soil health and towards intentional biological priming.

In the Australian context, with our weathered soils and increasingly volatile climate, biological priming is a risk mitigation strategy. It allows us to:

- **Unlock nutrients.** Accessing applied phosphorus and minerals already present in our soils.
- **Build a microbial workforce.** Use microbial pathways to convert residues into stable organic matter that holds nutrients and water.
- **Decouple yield from inputs.** Reduce the reliance on global supply chains for synthetic inputs.

Recommendations

To move the industry towards a more resilient, biologically enhanced, and biologically literate future I propose the following actions.

On farm

- **Upgrade your endophytes.** Trial primers applied on the seed or in-furrow applications of biological inoculants especially ones from high quality compost, such as Johnson-Su compost or vermicompost to ensure a robust microbiome from day one.
- **Audit your house.** Before investing in expensive biological systems, address the physical and chemical constraints in your soil. Understand your context to construct a workable solution.
- **Digest to release.** In high rainfall/biomass areas use biological digesters on crop residue to biologically bind nutrients before winter leaching occurs.
- **Principles matter.** Analyse your whole system through a soil health principles lens and make changes where needed.

For the Industry and Research

- **Validate.** Farmer groups, supported by national bodies, should assess the validity of these opportunities of biologically priming in cropping and horticultural systems.
- **Screen the native biome.** Harvest and isolate microbes from different geological and climate regions of Australia. Test them against our economically significant crops. These microbes are already adapted to our environment and may (as shown in Brazil) be able to defend from pathogens or help crops adapt to our environment.
- **Scale.** Look to the Brazilian model of scale. Farmers can make companies or co-operatives to create locally adapted biology at scale.

For Policy

- **Establish National Soil Principles:** Australia would benefit from a "Soil Health Framework" (similar to the NRCS principles) to provide a common language for extension and research.

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Appendix 1

SLC Group Biological Product List

Type	Species	Pest/Disease	Grown/Purchased
Fungus	Metarhizium anisopliae	Insect parasitoid	Both
	Beauveria bassiana	Insect parasitoid	Both
	Trichoderma sp.	Soil-borne disease	Purchased
	Paecilomyces sp	root-knot and cyst nematodes.	Purchased
	Cordyceps fumosorosea	Insect parasitoid	Both
	Pochonia chlamydosporia		Grown

Type	Species	Pest Disease	Grown/Purchased
Bacteria	Bacillus thuringiensis (BT)	Chewing insect larvae	Both
	Bacillus subtilis	Bio-stim and soil-borne disease suppression (PGPR)	Both
	Bacillus amyloliquefaciens	Bio-stim and soil-borne disease suppression (PGPR)	Both

Biologically Priming Soil

	<i>Chromobacterium subtsugae</i>	Insects and mites	Grown
	<i>Bacillus pumilus</i>	Plant growth promoter (PGPR)	Both
	<i>Pseudomonas fluorescens</i>	Bio Stim, P solubilisation (PGPR)	Both
	<i>Bacillus aryabhatai</i>	(PGPR)	Both
	<i>Bacillus velezensis</i>		Both

Type	Species	Pest Disease	Grown/Purchased
Virus	baculovirus Spodoptera	Fall armyworm <i>spodoptera frugiperda</i>	Purchased
	baculovirus Armigera	Cotton bollworm <i>Helicoverpa armigera</i>	Purchased
	baculovirus Chrysodeixis	Soybean looper moth <i>Chrysodeixis includens</i>	Purchased
	baculovirus Armigera	Caterpillar complex	Purchased

Type	Species	Pest Disease	Grown/Purchased
Others	<i>Bradyrhizobium</i> sp., <i>Azospirillum</i> sp.	Inoculations of soy, rhizobia and free living N fixing Bacteria	Purchased
	pheromones	Moths and Weevil	Purchased

Type	Species	Pest Disease	Grown/Purchased
Macro biologicals	Wasp - <i>Trichogramma pretiosum</i>	Parasite of moth butterfly Lepidoptera	Purchased
	Wasp - <i>Telenomus podisii</i>	Parasite of bed bugs	Purchased
	green lacewing - <i>Chrysoperla externa</i>	Predator - generalist	Purchased
	Predator mite - <i>Neoseiulus barkeri</i>	Predator - generalist	Purchased

Appendix 2

Common microbial strains in Australian Agriculture

Species Fungi	Use	Applied When
Mycorrhizal fungi <i>Glomus</i> spp.	P uptake, water efficiency, stress tolerance,	Seed coating, in-furrow, transplant
<i>Trichoderma</i> spp.	Fungal pathogen control, root stimulation	Seed, transplant, soil drench

Species Bacteria	Use	Applied When
<i>Rhizobium</i> spp.	Symbiotic N fixation in legumes (nodulation)	seed treatment (pre-sowing), in-furrow
<i>Bacillus subtilis</i>	Disease suppression, P solubilisation, ISR	Seed treatment, in-furrow, foliar
<i>Bacillus amyloliquefaciens</i>	Strong biocontrol + root growth stimulation	Seed, soil, early veg
<i>Azospirillum</i> spp.	Associative N fixation + root stimulation	Seed treatment, early vegetative
<i>Azotobacter</i> spp.	N fixation + phytohormone production	Seed treatment, soil application
<i>Pseudomonas fluorescens</i>	Disease suppression, phosphorus, iron scavenging, ISR	Seed treatment, early root stage

Appendix 3

Issues arising from making a compost extract. These are issues outside the scope of the study worth noting.

Aim	Questions arising
Extracting the microbes from the compost	Aggressively stir or bubble the compost in =>5 parts water to 1 part compost. At least 1 hour to release microbes and metabolites from compost.
Debris free usable extract that won't block spray filters	Some filter as part of the process of extracting. Others filter after extraction. Some allow the settling process post extraction to do most of the filtering. This is one of the most critical steps.
Extractable Efficiency	Not all the extract is usable in a boom spray application even post filtering, there is a layer of very fine solids that cause havoc in filters. Most people will draw the liquid from above these solids.
Apply in your circumstance	Application methods can differ for different crops. Boom, drone, boomless nozzle, dip and even drip irrigation with care.
Don't kill the microbes on the way out	Live microbes are sensitive to pressure and sharp corners. Don't wake up microbes if you want to use your existing boom spray.
How long is it safe to use?	Unlike other compost teas, JS extract can stay oxygenated for a long time. In some systems they believe weeks. But most are using it within a few days. Because the microbes are mostly dormant and are not pulling oxygen out of the water. If in doubt do the sniff test, if it still smells 'good' go for it. If not, pump it out and start again. <u>Do not use</u> . The 'Cress Test' is the ultimate on farm test for quality.

Appendix 4

Details of my Nuffield Travel

Travel date	Location	Visits/contacts
Week 1 March 2024	Canberra	Pre CSC
March 2024 Brazil	Brazil	Contemporary Scholars Conference (CSC)
April 2024	Argentina:	Agroforestry Tour
April 2024	New Zealand	Steve Sims, James Halford NZ – FAR Research farmers Pablo Gregorini – Department of Ag Science Lincoln University Agrimm - founder David Gale
2/06/2024- 7/06/2024	Indonesia	Global Focus Program
8/06/2024- 15/06/2024	France	
16/06/2024-22/06/2024	Denmark	
23/06/2024-01/07/2024	California	
2/07/2024-9/07/2024	Chile	
15 March 2025	QLD Australia	Joel Williams - Integrated Soils
16 March 2025		Kalfresh – Rob Hinrichsen
17 March 2025		Ian Moss F.A.R.M
19 March		Metagen – Shane Fitzgerald
20 March 2025	NSW	Michael Taylor Nuffield 2024
		Bio Bank Seed – Native seeds
22 March 2025	QLD	Rowan Berecny – Good Rich Fruit Co
23 March 2025		Woods Grain – Algae GFP Group trip
24 March 2025		Moonrocks - David Moon
24 June 2025		Claudia Ben Nuffield 2024
25 June 2025		Peter Attard
26 June 2025		Nutri Tech Solutions – Marco Gorgio
19 June 2025	UK	Rothamsted
23 June 2025	Vic-No Till tour UK	Wildfarmed offices London
		John Pawsey - Shimpling Park Farm
24 June 2025		David White - Hawk Mill Farm
		G's farm – Cambridgeshire
		Tom Pearson -
25 June 2025		George Sly - Horizon Ag
		Toby Simpson – Nuffield 2022
		Proctor Bros
26 June 2025		Glebe Farm - Andrew Mahom

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27 June 2025		Kingsclere Estates - Tim May Nuffield 2017
		Soil Bio Lab
		Lockerley Estate – Craig Livingstone
28 June 2025		Regen Ben
30 June 2025		Jake Freestone
		Rob Harvard
1 July 2025		Matthews Cotswold Flour
		FarmEd - Ian
2 - 4 July 2025		Groundswell Festival
7 July 2025	Netherlands	John Huiberts
9 July 2025		Biodynamic Berries
12 July 2025		Nuff
14 July 2025	France	Marie Morineau Nuffield Scholar 2024
15 July 2025		Firmin family farm
		Malo Family Farm
		Victor Leforestier Nuffield 2015
17 July 2025	USA - NY	Stone Barns – Blue Hill Farm
18 July 2025	PA	Dr James White Rutgers University
	PA	Rodale Institute
21 July 2025	Nebraska	Brian and Jenny Brhel
		Scott
22 July 2025		Ward Labs - Dr Ray Ward
		Green Cover – Keith and Brian
23 July 2025	Kansas	Doug Palen
	Phone call	Jim Williams - SD