September 2018

Soil Biology

THE MISSING LINK IN PASTURE PRODUCTION?

Evaluating the effects of biological and chemical amendments on soil biology and pasture biomass production.

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Glossary of Terms

Amendment – Anything added to pasture or crop soils, intended to improve production.

Bio TX 500-LP – The compost tea extract product of the YLAD company.

Biomass – Amount of living matter, expressed as the weight of organisms or plant matter per unit area.

Chemical nutrients – Plant nutrients in chemical form, intended to improve pasture or crop production. Syn. Fertilizer.

Compost Tea Extract – An amendment containing living microbes, produced by forcing water through compost.

Conventional farming – Refers to the use of fertilizers, herbicides, pesticides, tillage and monocultures.

Converte – The company that produces Converte Liquid Plantfood Concentrate, a microbe stimulant. In this report, the term "Converte" is also used to describe the product.

Fertilizer – Chemical nutrients added to pasture or crop soils to provide food for plants, intended to improve production.

Input – Syn. Amendment

Macronutrients – The main nutrients needed by plants: Nitrogen, phosphorous, potassium, magnesium, sulphur and calcium.

Micronutrients – Any of ten nutrients that are required in minute amounts by plants.

Monoculture – The cultivation of a single crop in a given pasture at one time.

Nutrient Cycle – The 'recycling' of vital nutrients from the physical environment into a living organism and back into the production of matter.

Plant-available – Nutrient(s) in a form that plants can absorb and use.

Plant nutrient – Any of 16 nutrients proven to be essential for plant health and growth.

Primary producer – Someone producing basic agricultural commodities (ie. farmer or cattle producer)

Soil biology – Living microorganisms in the soil; microbes.

Tillage – Preparation of soil for cultivation using digging, stirring or overturning.

YLAD – The company that produces Bio TX 500-LP Compost Tea Extract.

Abstract

Research has shown that pasture soil health and productivity is decreasing worldwide while climate change is increasing the challenges of primary production for graziers. While many *primary producers* increase their use of chemical *fertilizers* to boost production, new research indicates that soil fertility is actually increased by soil microbial activity. Using a variety of soil amendments, we tested the hypothesis that applying living microbes plus chemical fertilizers to soil will best increase soil health and pasture production.

Using 6 trial plots, various products and combinations of products were applied. Products included *plant nutrients* (fertilizers), and biological amendments: *compost tea extract* (a product containing soil microbes), and *Converte* (a microbe food and stimulant). *Soil biology* was tested at the start and end of the investigation, and the biomass produced was measured.

Soil biology testing showed substantial ecological and financial benefits of biological amendments. Benefits of both products weakened when combined with plant nutrients, and plant nutrients alone were hardly better than the control.

Pasture biomass production increased with plant nutrients on first cutting, while biological amendments increased production on second cutting. Further testing over a full growing season will provide more definitive data.

The investigation demonstrated that Converte and compost tea extract increased soil biological activity and pasture productivity. Plant nutrients were of some initial value in increasing biomass production, but suppressed soil biological activity.

Biological amendments are a cost effective, ecologically beneficial alternative to chemical fertilizers. Used correctly, these products could significantly increase the productivity and health of pasture lands worldwide.

Introduction & Inspiration

We live with our families on a 2300-hectare grazing property called 'Danthonia' in the New England region of NSW. Since the 1950's, the land has been conventionally managed, and when our families purchased it in 1999, we continued conventional farming. Our parents soon noticed the land's health deteriorating and production decreasing, even though the cost of inputs was rising. In an effort to reverse this trend, our farm manager, Johannes Meier, ran a trial with a relatively new grazing management technique called holistic grazing. The main concept in holistic grazing management is to reproduce natural grazing patterns. This means grazing concentrated groups of ruminants (cud-chewing livestock) on small areas of pasture for short periods, followed by long pasture rest periods. Amazingly, the paddocks trialed this way improved dramatically, so this technique was implemented across the entire property. In most paddocks, there was significant improvement, but in others, the plants did not grow well, and we believe there is still a fertility issue to address. This lack of good plant growth continued over the past years despite adequate rainfall and good grazing management.

Discussing this problem around the dinner table, we wondered if the lack of healthy soil biology (living microbes) could possibly be the problem, or contributing to it. This inspired us to do more reading, and was the spark for this scientific investigation. Following are some facts that we found fascinating:

> Humanity paid little attention to microbes for so long for a reason so simple a toddler would understand. We can't see them. Out of sight, out of mind. Literally…
>
> In all, there are an estimated 10 to the 30^{th} microbes on earth. That's a nonillion, a one followed by 30 zeros – 1,000,000,000,000,000,000,000,000,000,000. Although each microbe is too small to be seen, link them all together in a chain and they would stretch 100,000,000 light-years – well beyond the farthest visible star in the night sky… And all together, microbes are estimated to make up half the weight of life on earth.
> (Montgomery & Bikle, 2016, pp.24-25)

Other reading pointed to the fact that long term use of pesticides, fertilizers, and excessive *tillage* all negatively impact soil biology. We even discovered evidence that lack of healthy soil biology is affecting nutrient density and health value of plants grown for food. There is a rapid increase in the rate of auto immune and other medical disorders worldwide and growing concern that there is a link between this and the food we eat. To put it simply, lack of living healthy soil biology means a plant receives unbalanced nutrients and produces unbalanced food that is missing key *micronutrients*. This affects our health. So the state of our soils impacts each person that lives on the earth.

We decided to investigate whether a lack of soil biology could be the missing link preventing so many of our pastures from growing well. This investigation could be of great importance for farmers and graziers. Fertilizers are expensive, and often have limited benefit on unhealthy soils. Some soil scientists claim that these fertilizers are actually damaging the soil. If we can scientifically prove that improving soil biological health can increase pasture productivity for a reasonable cost, many primary producers can benefit ecologically and financially across Australia and the world. It may also be very beneficial to the next generation; if our food nutrition improves, the occurrence of many modern health disorders may naturally diminish. Compost tea extract is relatively inexpensive and can be produced on-farm. If there is an increase in any measured outcomes, the information will be significant in charting a course toward healthy and productive soil worldwide.

Could adding microbes or a microbe stimulant help improve soil biological health and increase plant growth and production? How would this compare to conventional fertilizers? We set out to discover an answer.

Our Aim

To determine what benefits, if any, are gained in soil biological health and plant biomass production by adding microbes, microbe stimulants and/or nutritional amendments to pasture soils that, through excessive tillage, fertilizer and herbicide application, have lost the fundamentals of healthy soil function.

Background Research

Overview

In nature, plants and soil microbes live in symbiosis. Soil microbes dissolve minerals in the soil and make them available to plants. These microbes selectively take up the correct amounts and ratios of nutrients that plants and people need. They also selectively prevent the uptake of toxic elements from the soil (Jehne, 2013). In exchange, the microbes are fed by exudates from the plants' roots.

Unfortunately, conventional agricultural practices have made plants dependent on fertilizer by suppressing or destroying soil biology and therefore the mechanism for plants to access nutrients from the soil. Those plants are now taking up nutrients provided by soluble fertilizers in the soil (rather than accessed by microorganisms) in whatever concentrations and ratios are present in the soil solution (Jehne, 2013). Studies show that nutrients (such as calcium, iron and vitamin C) have dropped approximately 30 percent in a variety of vegetables since 1975 (Sheer & Moss, n.d.).

Human Health

The famous twentieth-century agronomist William Albrecht warned humanity about nutrient-poor foods. He predicted that "industrialized agricultural soil would decline with human health following on its heels" (Montgomery & Bikle, 2016, 277).

Albrecht believed that microbial life was essential to soil health, making nutrients *plant-available*. We now know this to be a scientific fact. Albrecht also believed that nutrient-deficient soils "are related to many human health problems. These include many of the current auto-immune disorders" (Montgomery & Bikle, 2016, p.229). He even blamed deficient soils (which result in nutrient-deficient foods) for "general loss of mental acuity in the [human] population, leading to degenerative metabolic disease and early death" ("Soil depletion," n.d.).

Studies by French chemist André Voisin linked nutrient-deficient and imbalanced soils to many health problems, from birth defects and mental illness to diabetes and cancer (Brevik & Sauer, 2013). It is now thought that exposure to soil microorganisms can prevent allergies and immunity-related disorders (Brevik & Sauer, 2015).

On top of this data is the important fact that nearly "78% of antibacterial agents and 60% of new cancer drugs approved between 1983 and 1994 had their origins in the soil" (Brevik & Sauer, 2015).

Plant Health

It is commonly accepted that there are 16 nutritional elements that are essential to plant health. These elements must be in the correct form to be absorbed by plants (known as plant-available form) (Bareja, 2013). We will take a closer look at soil nutrients, what makes the nutrients plant-available, and how healthy soil functions to support plant life.

Plant Nutrients
The following table (*Figure 1*) lists the 16 essential "plant nutrients." It also demonstrates that the condition of the soil is vital to plant health.

ESSENTIAL PLANT NUTRIENTS

Element	**Forms Absorbed**	**Absorbed From**
1. Carbon (C)	CO_2	Soil or Atmospheric Carbon Dioxide and Water
2. Oxygen (O)	CO_2, O_2	Soil or Atmospheric Carbon Dioxide and Water
3. Hydrogen (H)	H_20	Soil or Atmospheric Carbon Dioxide and Water
4. Nitrogen (N)	NO_3^-, NH_4^+	Soil
5. Phosphorus (P)	$H_2PO_4^-$, HPO_4^{2-}	Soil
6. Potassium (K)	K^+	Soil
7. Calcium (Ca)	Ca^{2+}	Soil
8. Sulphur (S)	SO_4^{2-}	Soil
9. Magnesium (Mg)	Mg^{2+}	Soil
10. Iron (Fe)	Fe^{2+}, Fe^{3+}	Soil
11. Chlorine (Cl)	Cl^-	Soil
12. Manganese (Mn)	Mn^{2+}	Soil
13. Zinc (Zn)	Zn^{2+}	Soil
14. Copper (Cu)	Cu^+, Cu^{2+}	Soil
15. Boron (B)	BO_3^{3-}, H_3BO_3	Soil
16. Molybdenum (Mo)	MoO_4^{2-}	Soil

Figure 1. Table of Essential Plant Nutrients. Adapted from "List of Essential Plant Nutrients for Growth and Development," by Bareja, Ben G., 2013, *Crops Review,* Copyright 2010-18 by "CropsReview.Com and Ben G. Bareja."

Macronutrients
The main nutrients that plants require (macronutrients) are nitrogen, phosphorous, potassium, magnesium, sulphur and calcium.

- Nitrogen: Nitrogen is essential for plant growth. It makes up 16-18% of plant proteins and up to 3% of all plant compounds. In the soil, nitrogen is mainly in an organic form which is not available to plants. It must be converted into an inorganic form, either ammonium or nitrate.

- Phosphorous: Phosphorous is mainly concentrated in seeds and fruits but also moves to many organic compounds in plants. In the soil, a large portion of phosphorous is found in organic matter, which the plants cannot access, and in the soil. Soil biology breaks down phosphorous into the orthophosphate ion which is available to plants.

- Potassium: Potassium transports vital sugars throughout the plant's vascular system and promotes structural strength. Good soil structure is needed for plants to reach the potassium. Biochemical compounds which are produced by microorganisms improve the soil structure and the plant's ability to take up potassium.

- Magnesium: Magnesium is at the centre of each chlorophyll molecule and is therefore essential for photosynthesis.

- Calcium: Calcium is essential for plant structure and is needed in large amounts in the soil. Calcium deficiencies cause stunted roots and plant stress.

- Sulphur: Sulphur is essential in the synthesis of proteins and oils. Its absence limits photosynthesis. Soil biology is needed to make sulphur plant-available.

Micronutrients
Micronutrients are required by plants, but in very small amounts. They include boron, zinc, molybdenum, and others. Boron and zinc were both deficient in our pre-trial tests and are described below.

- Boron: Boron assists in moving plant sugars from leaves to roots, and is required for the uptake of macronutrients such as phosphorous and nitrogen. It is also essential for seed and fruit formation. Absence of boron causes stunted stem growth.

- Zinc: Zinc is a key element in enzyme and protein synthesis in plants. It contributes to plant growth and hormone production.

Soil Biology

Soil is a living environment and home to many organisms that contribute to plant health and survival. Many such organisms are visible to the naked eye, such as earthworms. However, millions of microorganisms such as bacteria, fungi, protozoa, and nematodes are also present and important for plants ("Understanding soil microbiology and biochemistry," 2017, p.2).

Soil is the main platform for the earth's cycles of carbon, water, and other nutrients, such as nitrogen and phosphorus. In healthy soil, the nutrients are stored and transformed there. This *nutrient cycle* is vital to plant health ("Nutrient cycling," 2011).

Decomposition is at the heart of nutrient cycling, and involves most of the biology in the soil:

> Arthropods and earthworms chew the material and mix it with soil. A few fungi may break apart one complex compound into simpler components, then bacteria can attack the newly created compounds, and so on. Each organism gets energy or nutrients from the process. ("Nutrient cycling," 2011)

Decomposition frees carbon and other nutrients from organic forms, "putting them back into biological circulation" ("Nutrient cycling," 2011). Even microbes that die leave the nutrients they've consumed fixed in the soil.

Organic matter that is not decomposed is crucial, too. Soil biology transforms it into organic compounds called humates. Humates can remain in the soil for hundreds of years, storing nutrients and improving overall soil structure ("Nutrient cycling," 2011).

Microbes in the soil enable soil particles to stick together into pea sized lumps called aggregates. Between aggregates there is space which allows moisture and oxygen to enter easily. The aggregates then absorb the moisture and protect it from evaporation (Jones, 2018, p.4).

Bacteria
A single gram of healthy soil can contain billions of bacteria ("Understanding soil microbiology and biochemistry," 2017, p.4). There are about 60,000 species of bacteria, most of which live in the top 10 centimetres of soil where organic matter is abundant (Reid & Wong, 2005). Following are some examples of the important functions of soil bacteria:

- Decomposing bacteria decompose organic matter (in the presence of water.) As the organic matter breaks down, the nutrients dissolve into the soil, where they are plant-available (Reid, 2005).

- Sulphides, which are important to plant health, are in a form which plants cannot access. Thiobacillus bacteria convert sulphides into plant-available sulphates (Reid, 2005).

- Rhizobium bacteria extract nitrogen gas from the air and make it plant-available. This form of nitrogen fixation is equivalent to the addition of 100 kg of nitrogen per hectare per year (Reid, 2005).

- Some bacteria suppress crop diseases and have been commercialised worldwide for this use. Some break down toxic substances (Reid & Wong, 2005).

- Actinobacteria break down humates. They live symbiotically with plants, fixing nitrogen in the soil for the plants in exchange for saccharides from the plants root exudates ("Actinobacteria," n.d.).

- Bacteria excrement and dead bacteria contain the nutrients they've eaten, fixing them in the soil (J. Meier, personal interview, 08 January 2018).

- The excrement of Actinobacteria is extremely useful in human medicine, producing antifungals, antibacterials, antivirals, immune-modifiers and more ("Actinobacteria," n.d.).

Fungi
Fungi thrive in organic matter with a high carbon content. Soil fungi grow in long thread-like structures or hyphae that form a mass called mycelium. This mass colonises plant roots, and actually draws nutrients from the soil and decaying matter to the plant roots (Jones, 2018, p.6). Fungi can also survive droughts by living in dead plant roots.

Fungi serve the following functions:

- Transport nutrients via mycelium to plant roots.
- Mutualist fungi live on or in plant roots and help the plant obtain water and nutrients. Mycorrhiza, one of the best known mutualists found naturally in all soils, deliver 11 of the 16 elements essential to plant health.
- Mutualist fungi mass protects plant roots from pests and pathogens.
- Fungi mass increases root area through which a plant can obtain nutrients (Jenkins, 2005). In exchange, plants provide carbon to the fungi. When this exchange is healthy, as much as 60% of the carbon in a plant's living tissues can be channelled directly to the soil, where some of it is fixed with biologically fixed nitrogen (Jones, 2018, p.6).
- Fungi mass helps soil resist compaction and erosion ("Mycorrhizae benefits: Application and research," n.d.).
- Fungi excrete glomalin, a substance which creates aggregates, giving the soil better structure and higher organic matter content ("Mycorrhizae benefits: Application and research," n.d.).

Other Organisms
Protozoa living in the soil feed on bacteria, other protozoa, soluble organic matter and fungi. Their primary plant-supporting function is to release plant-available nitrogen into the soil. They also help regulate bacteria population; as they graze on bacteria, it actually stimulates the growth of the bacteria population. (The exact cause of this connection is still unknown) (Ingham, 2016b).

Nematodes are microscopic non-segmented worms. There are many species which feed on a variety of microbes, some of which are disease-causing. They disperse bacteria and fungi along plant roots and in the soil by transporting live and dormant microbes on their bodies and in their digestive systems. Nematodes are also an important component of nutrient cycling in the soil (Ingham, 2016a).

Not all microbes are beneficial to plants. For instance, anaerobic bacteria which thrive in damp, poorly drained soils, produce toxic compounds that limit root growth and make roots prone to disease (Reid & Wong, 2005). Pathogenic fungi such as verticillium, phytophthora, rhizoctonia, and pythium penetrate and decompose living tissues, resulting in either a nutrient-deficient plant or death (Jenkins, 2005). Some nematodes, rather than feeding on disease-causing organisms, actually cause disease themselves (Ingham, 2016a). However, in healthy soils with good drainage, beneficial microbes can out-compete detrimental microbes (Jenkins, 2005).

The Rhizosphere

The rhizosphere is a 1 millimeter zone around the root where a number of important biological and chemical processes take place. Microorganisms living in the rhizosphere share a symbiotic relationship with plant roots. As a by-product of photosynthesis, roots exude simple sugars, amino acids, organic acids, and carbohydrates, all of which feed the microorganisms. In addition, these plant root exudates are the primary source of carbon that can be stored long term in the soil as humus (Jones, 2018, p.1). In addition to converting soil nutrients to plant-available forms, microorganisms produce vitamins, antibiotics which defend the root from pathogens, and hormones which aid plant growth (Lines-Kelly, 2005). Root exudates determine which microbes colonize the rhizosphere of any given plant:

> Research reveals that substantial differences in the microbial species associated with plants growing in the same soil are attributable to the particular composition of root exudates that a plant pumps out. In other words, plants have the power to draw particular microbes to them (Montgomery & Bikle, 2016, 100).

This, of course, implies that microbes can be selective about the exudates they'll accept:

> Different species of microbes have distinct preferences, and all are selective about what root exudates they'll take up. And they'll modify exudates too, for their own purpose, of course, but sometimes in ways that benefit the plant. For example, … bacteria can turn tryptophan [a root exudate] into a plant growth hormone…. In this way plants use microbial preferences to their own advantage, capitalizing on the fact that a different crowd will show up depending on what is available at the subterranean smorgasbord (Montgomery & Bikle, 2016, 101).

Root exudates also keep the soil around the roots moist, and improve the soil's overall structure (Reid, 2005). And like decomposition, plant-microbe symbiosis is vital to transferring and stabilizing carbon in the soil as stable humus.

Soil Health Restoration

Research has revealed strong support for the following principles of soil restoration.

- For healthy fungi and bacteria, provide organic matter. This can be done through green, multi-species manure cropping (cover crops that get ploughed into the soil as fresh compost), mulching and holistic grazing management (Reid & Cox, 2005).

- Reduce tillage, which harms the soil in multiple ways. It exposes the soil to the air and the sun, so the soil loses moisture (good for fungi and bacteria) and carbon (food for soil biology,) and the sun kills some of the microbes. Tilling also cuts through the important hyphae of the fungi, and subjects the soil to erosion.

- Stimulate high biodiversity among soil microbes, so that native organisms can out-compete dominant pathogenic organisms (Jenkins, 2005).

- Make an effort to counteract soil compaction and neutralise acidic conditions (Reid & Wong, 2005). It is hard to increase bacteria populations in poor soil by simply adding bacteria, because the low population is due to unfavourable conditions to begin with (Reid & Cox, 2005).

- Cover the land with crops for as much of the year as possible, again because any soil that is exposed to the air is losing carbon, nitrogen and moisture (Reid & Wong, 2005). Additionally, all green plant growth increases the movement of carbon from the atmosphere to the soil.

- Grow a diversity of plants because this increases the diversity of microbes. *Monocultures* need increasing levels of fertilisers, fungicides, insecticides, and other chemicals that decrease soil biological activity. Biologically diverse systems do not need these chemicals to thrive (Jones, 2018, p.6).

- Limit chemical use. Because unhealthy soil is lacking in microbes, fertilisers do not help; in fact, applying fertiliser often has negative effects. Inorganic nitrogen and phosphorous are very destructive because the plants no longer need to transfer carbon to the soil to receive these essential elements. This limits the food for microbes that are involved in obtaining minerals and trace elements. The lack of these elements increases the susceptibility of plants to pests and diseases (Jones, 2018, p.6). In addition, pesticide and herbicide use has a direct negative effect on soil biology.

- Use management-intensive grazing techniques. Grazing animals correctly can promote plant growth and soil health. These animals carry many of the same microbes in their digestive tracts as what is in healthy soil. Therefore, animal excrement actually transports good soil biology around the grazed area, and supplies the soil biology with valuable nutrition. Additionally, areas that are grazed at the right growth stage in a season (with a sufficient period of rest and plant growth between grazing) receive maximal carbon in the soil (from root exudates) compared to an area that is grazed once. This allows nutrients to be cycled multiple times in one growing season (J. Meier, personal interview, 08 January 2018).

Soil Products Research

The products researched below are available to us locally, are considered safe for the environment, and were within our moderate budget for this project. They also fit into the categories of Plant nutrients, Microbes and/or Microbe stimulants.

Plant Nutrients

1. OzCal (prilled lime – finely ground and manufactured into small balls)

   Description: Ozcal is a highly plant-available source of calcium for treatment of calcium-deficient soils.

   Benefits:

   - Quick establishment and healthier growth of crops and pasture
   - Improves crop and pasture yield
   - Fast crop response (Nutrifert Australia, 2015)

2. OzGyp (prilled gypsum - calcium sulphate)

   Description: A source of plant-available calcium and sulphur. When dissolved in the soil, calcium is released as the main nutrient, plus sulphur which is essential for nitrogen metabolism. pH of soil is not altered by gypsum.

   Benefit: Due to fineness of product, nutrients are released rapidly, giving plants easy access to quality calcium and sulphur (Nutrifert Australia, 2016).

3. Amino Max

   Description: Amino acids in liquid form, derived from enzymatically digested plant protein.

   Benefits:

   - Highly effective natural chelating agent. (A chelating agent's primary benefit is to bind insoluble minerals in alkaline soils to make them available to plants) ("Chelation and live organic soils," n.d.).
   - Source of energy-efficient plant nitrogen
   - Contains several amino acids that are recognized plant growth hormones (Nutri-Tech Solutions, 2018)

4. Zinc Sulphate

   Description: Plant-available elemental zinc in powder form.

   Benefits:

   - Zinc is an essential micro-nutrient that governs leaf size and so is critical for photosynthesis.

- Because photosynthesis provides sugars to microbes via root exudates, zinc is key to a healthy soil microbe population.

5. Inkabor's Boron

   Description: Plant-available elemental boron in powder form.

   Benefits:

- Boron is essential for the growth of plants, providing structure to cell walls.
- Helps with pollination, fruit and seed development
- Plays key role in movement of sugars from plant leaves down to roots

6. Ollsen's Liquid Sea Minerals

   Description: A natural blend of minerals, trace elements and nanoparticles needed for plant production, including magnesium, calcium, potassium, sodium, and 40 other elements.

   Benefit: Supplies worn out, deficient soils with a balanced supply of minerals and trace elements (Ollsen's, 2018)

Microbes

Bio TX 500-LP Compost Tea Extract (produced by YLAD company)

Description: Fungal-dominant compost tea extract. A water-based extraction made of the soluble minerals, humic substances, and diverse microbes from healthy humified compost.

Additionally, these foods for the microorganisms were added to the extract by the producer (YLAD) to feed the biology prior to soil application:

1. Liquid Fish: Contains amino acids, vitamins, fatty acids and micro and macro nutrients (YLAD Living Soils, 2018)
2. Molasses: Liquid sugar product

Benefits:

- Raises soil organic carbon levels
- Increases plant root size
- Increases soil's water holding capacity
- Helps unlock tied up minerals
- Increases diversity and ratio of beneficial soil microbes
- Reduces nutrient leaching (YLAD Living Soils, n.d.)

In 2012, a trial was undertaken in Young, NSW to compare the application of 100 kg urea vs YLAD Compost Tea Extract.

- Both paddocks were sown with Wedgetail wheat and given 80 kg of starter fertilizer (MAP).
- The control paddock received 70 kg of urea. The YLAD paddock received Compost tea extract.
- Both paddocks were then grazed for the same number of days.
- Next, a leaf test was performed to determine what nutrients the crop lacked. The result showed that the crop was deficient in phosphorous, copper, boron, and zinc but high in nitrogen.
- The control then received an additional 100 kg urea.
- The YLAD paddock received a $30/ha fertilizer which contained compost extract, 10 kg of solubilized urea, trace minerals, and humic acid.

2012 Harvest results:

- Control paddock yielded 5 tonnes/ha but also had many weeds
- The YLAD paddock yielded 6 tonnes/ha and few weeds
    - Because urea cost more than the foliar fertilizer, a profit of $10,000 was made using the YLAD product over urea (Nelson, 2018).

Microbe Stimulants

Converte Liquid Plantfood

Description: A natural balanced plant food designed to feed the soil microbiome. Contains mineral trace elements, seaweed extracts, phyto-proteins, and vitamins.

Benefits:

- Provides essential elements for plant growth
- Feeds microbiome while providing prophylactic levels of trace elements and minerals to avoid hidden deficiencies
- Promotes nitrogen fixation and phosphorous availability
- Promotes mycorrhiza which increases nutrient feed to roots
- Improves nutrient transfer to plants via chelation
- Improves soil water holding capacity
- Increases soil organic matter
- Improves soil aeration and drainage
- Decreases nutrient leaching (Converte Health, 2017)

Converte Plantfood Wheat crop trial, 2017-2018 season, Currawarna NSW

Elmore wheat crop trial, comparing Converte to conventional treatments. Half of the 40-hectare paddock was treated with conventional fertilizer and half paddock was treated with Converte plantfood in May 2017 at a rate of 2.5 litres per hectare.

2018 Harvest results:

- Converte treated area yielded 3 tonnes/ha
- Conventional area yielded 2.5 tonnes/ha
- Crop inspection after spring frosts showed less frost damage and healthier plants in the Converte treated area (YLAD Living Soils, 2015).

Conclusion of background research

Poor farming practice over decades including excessive tillage, fertilizer and herbicide use has damaged the ecology of soils worldwide. Soils thus damaged become unbalanced in nutrients, do not produce well, and do not provide a healthy habitat to soil biology, which is vital to providing nutrients to plants. Perhaps we can measurably increase soil biological activity by adding plant nutrients, microbes or microbe stimulants. If soil biological activity is increased, it may result in increased plant growth and quality.

Hypothesis

We expect that we can best increase the biological function and productivity of the soil by adding microbes and nutrients to the soil. Of the products locally available that we researched, compost tea extract with plant nutrients will likely provide the most benefit, as measured by plant biomass and soil biological activity.

Investigation

Selection of Site

The selection of the site was based on the following parameters for reliable and valid results.

- Located in a paddock that has not performed well despite holistic grazing management.
- Located in a paddock that was cropped until 2007, exposing it to herbicides, tillage, and erosion for many years.
- Even distribution of plants (as much as possible)
- Even slope, in full sun

Risk Assessment

Our investigation will expose us to numerous potential hazards:

- Electric fencing: To protect our plots from cattle, we use 8000-volt low amperage fencing. Bodily contact can cause severe electric shock. To avoid this, we will use caution near fences and observe our farm safety rules.
- Farm machinery: There is the potential for injury when using utility vehicles for transport on the farm. Lawn mowers can cause serious cutting injuries and injuries from thrown objects (rocks, sticks, etc.) Because of this we will only visit our site under adult supervision, and will wear PPE (personal protective equipment) appropriate to the tasks being done.
- Environmental hazards:
    - Excessive sun exposure is dangerous because it can cause sunburn, dehydration, and long term ailments such as skin cancer. Much of our data collecting will be done outside; therefore, we will wear sunscreen and protective clothing.
    - Our property is home to many venomous and deadly snakes, commonly seen in paddocks such as the site of our trial plots. We will have a snake bite kit with us at all times in the paddock, and wear sturdy footwear to protect from bites.
- Other hazards: When testing for pasture productivity, we will be using sharp scissors to cut the plants. This has the potential for causing injury. To avoid accidents, we will make sure the cutting space is free of appendages and carry a first aid kit with us.
- Chemical exposure: The products we intend to trial do not pose a significant exposure risk, both because the products are generally quite safe, and because the amounts we will be exposed to are minimal. We will, however, follow the manufacturers' advice to wash our hands after use.

Preparation of Plots

After site selection, the following steps were taken to create plots.

- An area in the nominated paddock was chosen for relative uniformity of plant numbers and ground cover.
- Entire site was mowed to a height of 100mm.
- Using a template, each plot was staked out at 2 meters by 1 meter, and 1.5 meters apart.
- Star pickets were put at the corners of each plot.
- String was laced around the pickets, marking each plot's boundaries.
- Signs were made and placed to distinguish between various treatment applications.
- The entire site was fenced off using 2 strands of electric fencing braid connected to main electric fence to prevent cattle entering trial site.

Pre-application Soil Analysis

- Chemical soil analysis of the nominated paddock was carried out by Environmental Analytical Laboratories (EAL) 2 months prior to beginning of investigation.
- Vic Milward, an agronomist of Resource Consulting Service (RCS), gave recommendations regarding plant nutrients and microbes (compost tea extract) based on chemical soil analysis.
- Biological soil analysis was carried out in January 2018, by Microbiology Laboratories Australia (MLA) under Dr. Maria Manjarrez, prior to application of trial plot amendments.
- Converte Liquid Plantfood Concentrate was noticed by our farm manager at the AgQuip agricultural field day event in August 2017. When discussing this investigation, he suggested the product, and we decided to trial it.

Trial Soil Amendments

Product Choice

We chose to trial the following soil amendments based on our background research, laboratory testing of our soil, laboratory and agronomical advice regarding our soil, and information we obtained about the products:

- Plant nutrients. According to agronomist Vic Milward of RCS, the results from our soil chemical analysis showed that our soil needed:
    - Calcium
    - Sulphur
    - Amino Acids
    - Zinc
    - Boron
    - Potassium
    - Trace nutrients
- Microbe stimulants: Converte Liquid Plantfood Concentrate.
- Microbes: YLAD's Bio TX 500-LP Compost Tea Extract.

Labeling

Early in the investigation, we made signs to mark the plots according to the applications they would receive. At that time, we thought to label the plots as follows (as seen in the photos in Appendix A):

1. Control
2. Soil amendments
3. Converte
4. Converte with soil amendments
5. Compost extract
6. Compost extract with soil amendments

We later realized that these labels were somewhat ambiguous, and we settled on the following for our reports and data analysis:

1. Control
2. Plant nutrients (previously 'soil amendments')
3. Converte (microbe stimulant)
4. Converte (microbe stimulant) + plant nutrients (previously 'soil amendments')
5. Compost tea extract (microbes)
6. Compost tea extract (microbes) + plant nutrients (previously 'soil amendments')

Application
Amendments were applied to plots as follows:

- Control (No products applied)
- Plant nutrients
  - Zinc sulphate 0.2 mg
  - Inkabor Boron 0.2 mg
  - Amino Max 0.1 ml
  - Liquid sea minerals 0.3 ml
  - Ozgyp 20 grams
  - Ozcal 20 grams
- Converte Liquid Plantfood Concentrate (microbe stimulant) 0.5 ml
- YLAD's Bio 500 TX-LP Compost Tea Extract (microbes) 20 ml/2 m2
  - (YLAD combines their compost tea extract with the following two ingredients. While these are technically microbe stimulants, for the sake of this trial, we simply tested the combination product as living microbes. The rationale is that in order for the microbes to survive transport and application, they must have some form of food.)
  - Liquid Fish 0.6 ml/2 m2
  - Molasses 0.4 mg/2 m2
- Compost tea extract + plant nutrients (amounts as above)
- Converte + plant nutrients (amounts as above)

To remove the variable of rainfall, each plot was watered with 30-50mm rain water after amendment application and then whenever it was dry. [Dates in log book, Appendix A.]

Analysis
We will analyze measurable differences in soil biological testing indicators and pasture biomass production in response to applications (either alone or combined) of:

- Microbe stimulants: Converte Liquid Plantfood Concentrate.
- Microbes: YLAD's Bio TX 500-LP Compost Tea Extract.
- Plant essential nutrients: Chemical fertilizers.

Data Collection Techniques

1. Soil tests:
   a) Biological soil analysis (MicroWise and ActivityWise):

      Test # 1 (Pre-application) 20 January 2018

      Test #2 (5 months post-treatment) 21 May 2018

      The purpose of these tests was to identify and evaluate the microbes in the soil. To make sure the method was accurate and consistent, we:
      - Used the Microbiology Laboratories Australia guidelines.
      - Made sure all sampling was done at the same depth.

- Because microbial activity varies with time of day, we took samples between 12 and 2pm for both tests.
- Froze samples promptly to preserve microbes until testing.

Apparatus:

- Core sampler
- Clean zip lock bag
- Cooler box with ice (Required to keep samples cool until taken to freezer)
- Permanent-ink pen

Procedure:

- Label bag for area to be tested
- Ensure core sampler is clean and rinsed with rain water
- Locate site for core sample, 2.5cm from the edge of any plant to ensure consistent sample (per microbiology lab instructions.)
- Put core sampler tip on ground, apply downward pressure and rotate tool until a depth of 10 cm is reached.
- Carefully pull core sampler from ground and gently remove core of soil.
- Place soil core in labelled bag. All cores from one plot will go in this one bag.
- Repeat this process.
  - Test #1, repeated process 4 times, ensuring that samples are taken at even intervals around the site.
  - Test #2, repeated 5 times, taking a sample from each test plot.
- Seal Ziploc bag and place it in the cooler box with ice.
- As soon as possible, transport to freezer and store at -18 C.
- Ship Next Day Air to Microbiology Labs Australia.

b) Chemical soil analysis (pre-trial): The purpose of this test is to measure nutrients in the soil. The test measures both plant-available nutrients and total nutrients.

Apparatus and procedure are as above, with the following exceptions:

- We took 20 cores, in a transect across the paddock as per laboratory instructions.
- Freezing the samples was not necessary, as nutrients do not die or disappear at normal temperatures.

2. Pasture biomass production: This test measures the amount of plant material that grows in a given area over a certain time period, usually on a per hectare basis. It indicates pasture performance and growth.

Apparatus:

- 3-dimensional template (300mm x 300mm x 150mm high)
- Large scissors

- Large plastic bags
- Permanent-ink pen
- Digital gram scale

Procedure:

- Monitor plots to see when plants flower (indicating full growth). When they do:
- Label six bags, one for each plot.
- In each plot, place template over plants ensuring all plants are upright.
- Holding plants upright from the top, cut level with top of template, 150mm.
- Move template and repeat as necessary until entire plot has be cut.
- Place plant foliage in bag labelled for appropriate plot.
- Repeat for all 6 plots.
- Take bags to dry warm location. Leave open and allow to dry for approximately 1 week until dry to the consistency of hay.
- When dry, weigh the harvested plant biomass from each plot to the nearest gram.
- Record results.
- Spread plant biomass on the plot it was harvested from. (This replicates natural grazing. When animals graze, they eat approximately 1/3 and the remainder is trampled back to the ground and broken down and recycled by soil microbes. As animals graze, their excrement, containing digested plant biomass, is also spread on the area.)

Test Descriptions

Soil Biology Tests

Soil biology testing was carried out by Microbiology Laboratories Australia and included 2 separate tests: ActivityWise and MicroWise.

ActivityWise (AWSE)

This test measures microbial activity in soil, microbial biomass carbon, microbial respiration, and phosphorous and nitrogen release on rewetting of the soil. The following is an explanation of this test provided by the laboratory.

Explanations

Microbe Activity Wise Plus measures activity of soil microbes directly from your sample. It measures the amount of carbon dioxide (CO2) emitted by microbes over time to calculate Microbial Activity, Soil Basal Respiration (SBR), Soil Microbial Biomass Carbon (C) (SMBC), and the nitrogen (N) and phosphorus (P) released after a drying-rewetting event (such as 'season break' after a hot, dry summer). Most soil microbes under aerobic conditions (the state your soil should be in) convert carbohydrates into energy and CO2, which they emit as a waste product, just like animals, plants and humans. This is used to calculate the Microbial Activity Indicator (0 to 100) based on known values for soils. Correlations published in scientific journals are also used to estimate soil basal respiration (SBR, 7-28 day), soil microbial biomass C (SMBC), and N and P release (0-28 day) after a drying-rewetting event. Soil Basal Respiration is the normal, steady rate of respiration in a soil. Soil Microbial Biomass C is the amount of C held in the microbial biomass. N and P held in microbial cells are released in a sudden flush when soil is re-wet after drying. These values reflect the quantity and quality of soil carbon, and other microbially assistive nutrients (e.g., N and P). CO2 concentration in the air around many crops is often a limiting factor to growth during peak production. Stomata, the pores plants use to take in CO2, are located on both sides of the leaf (dicotyledons have more on the underside), which allows plants to use the CO2 emitted by soil microbes as it rises from the soil. Having a good level of microbial activity in your soil not only helps soil processes, but can also help to improve crop growth. N and P released after a drying-rewetting event are a source of plant nutrition that can also improve crop growth. However, it is important to note that not all of the amounts released will be plant available; some will be immobilised into non-labile, recalcitrant and microbial nutrient pools. Always compare your results with a control sample. Guide values are included as a help, but because a large number of factors affect microbiology the guide levels may not be optimal for your specific conditions. Visit www.microbelabs.com.au for more information.

MicrobeWise (MWSE)

This test measures the biomass of key microbial groups. MWSE measures a range of microbial indicators including nutrient accessibility, nutrient solubilisation rate, drought resistance, disease resistance and residue breakdown rate. It also measures microbial diversity, fungi to bacteria ratio, bacterial stress, and total bacterial and fungal organisms, focusing on key groups important to soil processes. It measures organisms that are alive or recently dead (within a few days).

MWSE is a snapshot of soil biology at the time of testing and is influenced by soil moisture, soil temperature, and other factors.

Plant Biomass Production Analysis

This test measures the weight in grams of plant biomass produced from each plot, at the time of each cutting. It was carried out by ourselves, on site.

We measured cost of amendments compared to kg/hectare of biomass produced and value of beef produced (a theoretical assessment). These measurements are commonly used in agriculture to help farmers assess actual returns in biomass or value of beef in dollars compared to dollars spent on soil amendments.

Results & Data Analysis

The charts that follow summarize and analyze the test findings. Official laboratory test results can be found in Appendix B.

ActivityWise Results

Microbial Activity Indicator
This test measures microbial activity in the soil with higher levels indicating better overall soil health.

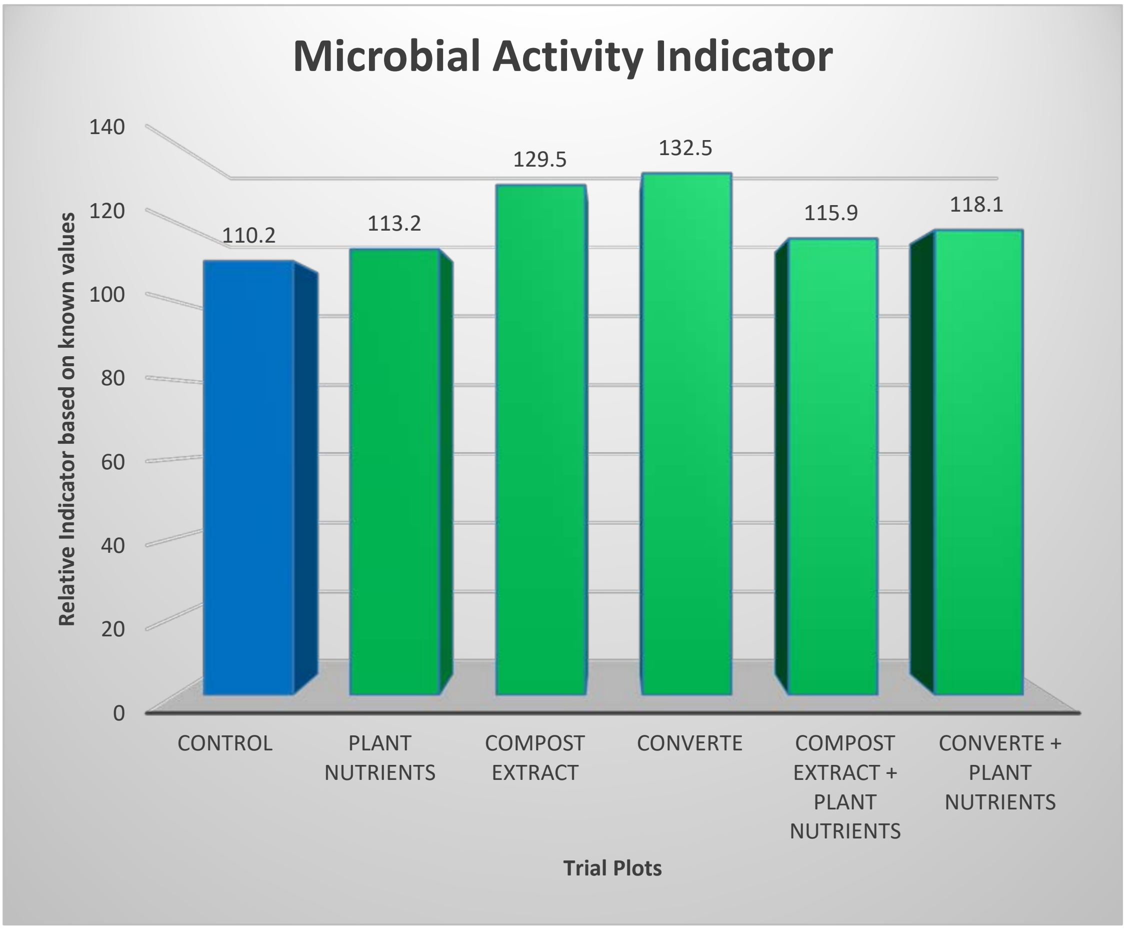


Figure 2: Microbial Activity Indicator results

Analysis: Microbes and microbe stimulant amendments showed the greatest improvement in soil microbial activity (Converte 20.26% better than control, compost tea extract 17.5% better.) Combining these amendments with plant nutrients lessens the positive effects. (Converte with plant nutrients was 7.17% better than control while compost tea extract with plant nutrients was 5.17% better.) With plant nutrients alone, microbial activity was only slightly better than the control (2.7%). These results indicate that if plant nutrients are added, the plant has the nutrients it requires and does not provide root exudates to feed soil biology, leading to less biological activity in the soil.

Soil Microbial Biomass (Carbon)

This test measures the carbon (C) held in microbial biomass with higher levels indicating better overall microbe and soil health. Soil properties such as clay content, pH, and available soil carbon influence microbial biomass.

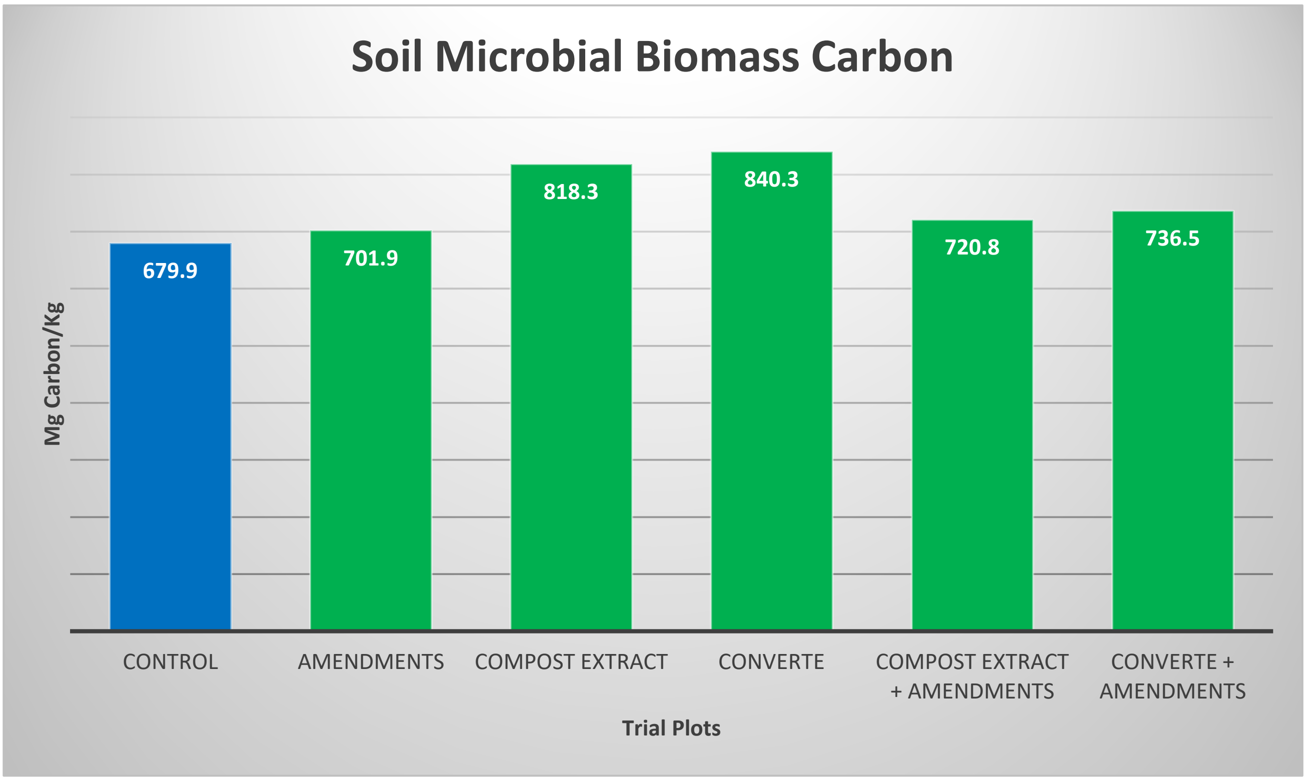


Figure 3: Soil Microbial Biomass Carbon results

Analysis: Microbe and microbe stimulant amendments showed greatest improvement in soil microbial biomass C (SMBC). Converte SMBC was 23.5% greater than control, and compost tea extract was 20.3 % greater. The plant nutrients plot was only 3.2% more than control. Compost extract and Converte, both with plant nutrients, were only slightly higher than plant nutrients alone (6 and 8.3% more than control, respectively.)

These results indicate that microbes and microbe stimulants measurably increase SMBC, while plant nutrients have very little positive effect on SMBC. The mechanism may be that plants have all the required nutrients and do not feed soil biology with root exudates, leading to less biological activity in the soil. Mixing microbe and microbe stimulant amendments with plant nutrients lessens the positive effect of the soil biology.

Microbial Respiration
This test measures carbon dioxide (CO_2) released from the soil between 7 and 28 days after soil sampling, and indicates the number of microbes in the soil. Higher levels indicate more biology.

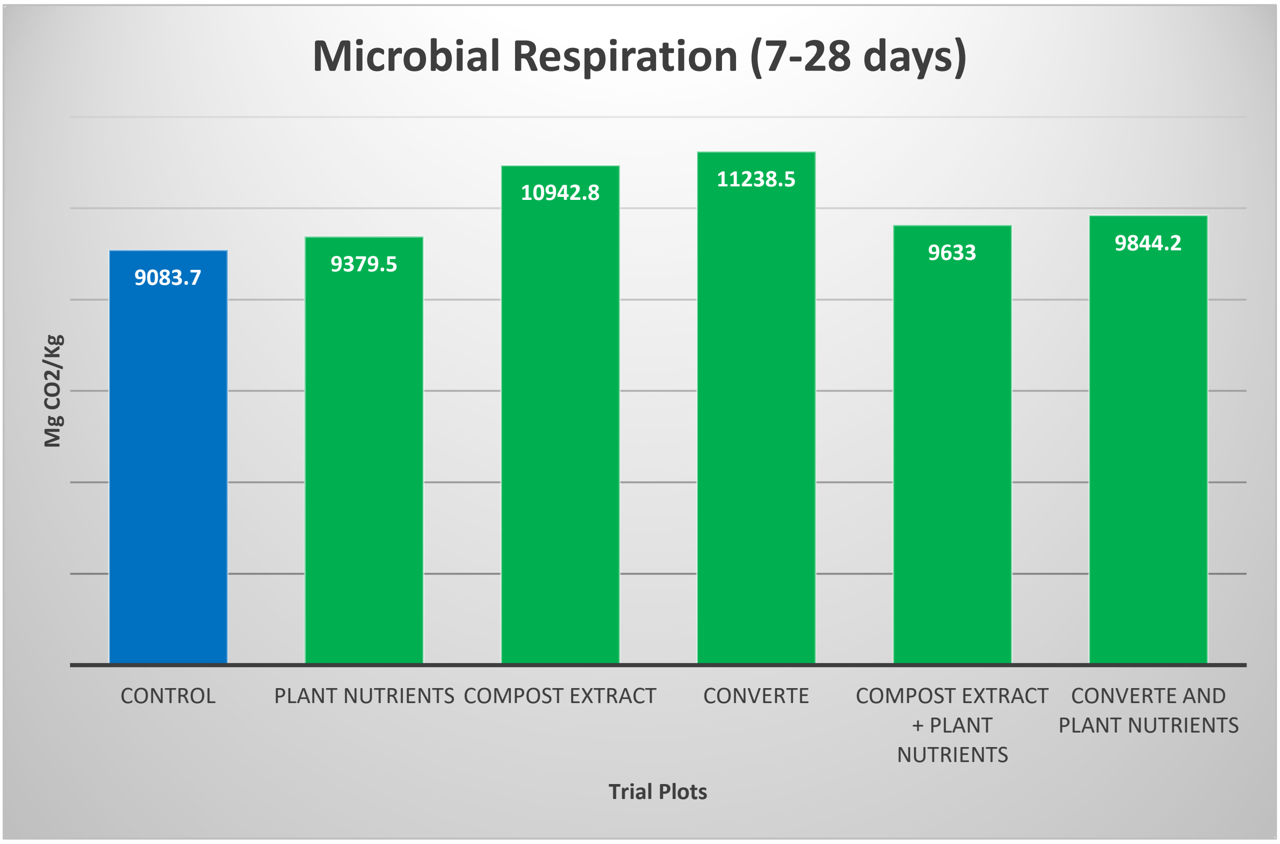


Figure 4: Microbial Respiration (7-12 days) results

Analysis: The results show that microbe and microbe stimulant amendments released the most CO_2 from the soil, indicating that these two amendments had the greatest benefit on microbial activity and mass.

Phosphorous Release on Rewetting of Soil
This test measures the release of phosphorous (P) stored in microbial cells following a drying and then rewetting event, such as the end of a drought. It is measured in kilograms per hectare, with values representing kilograms of P more than what was released in the control plot. The phosphorous is plant-available.

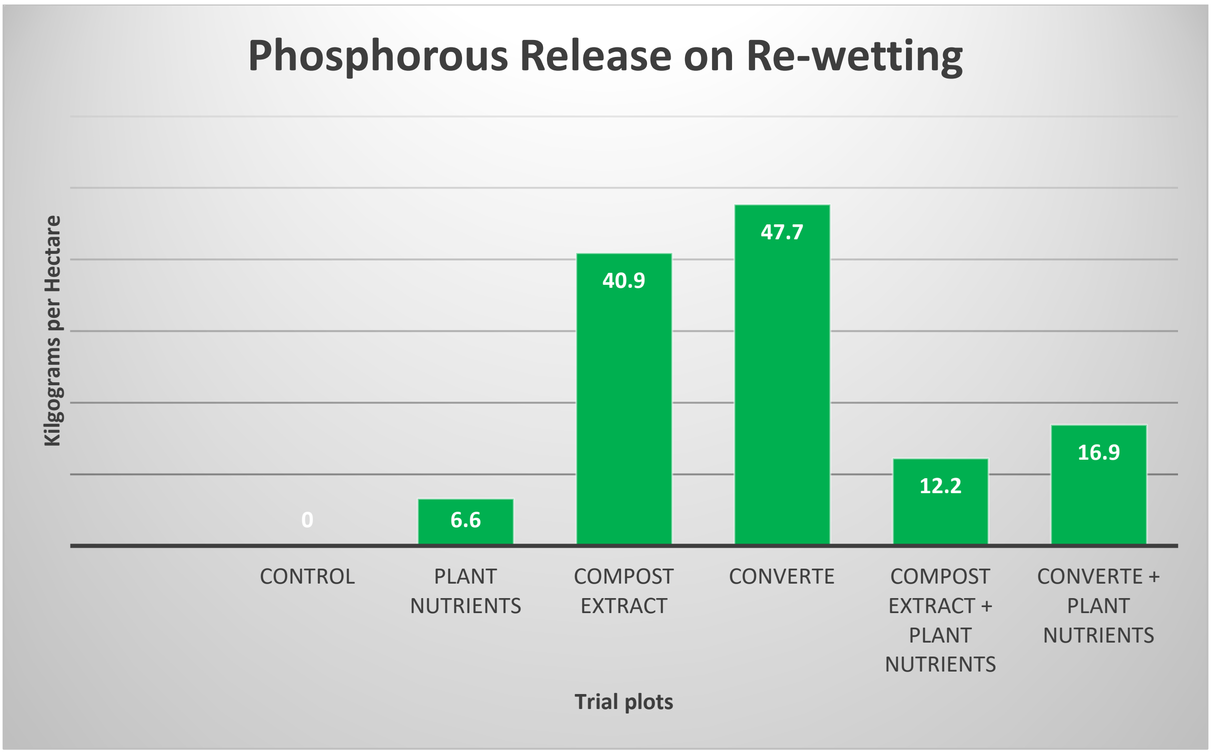


Figure 5: Phosphorous Release on Re-wetting results

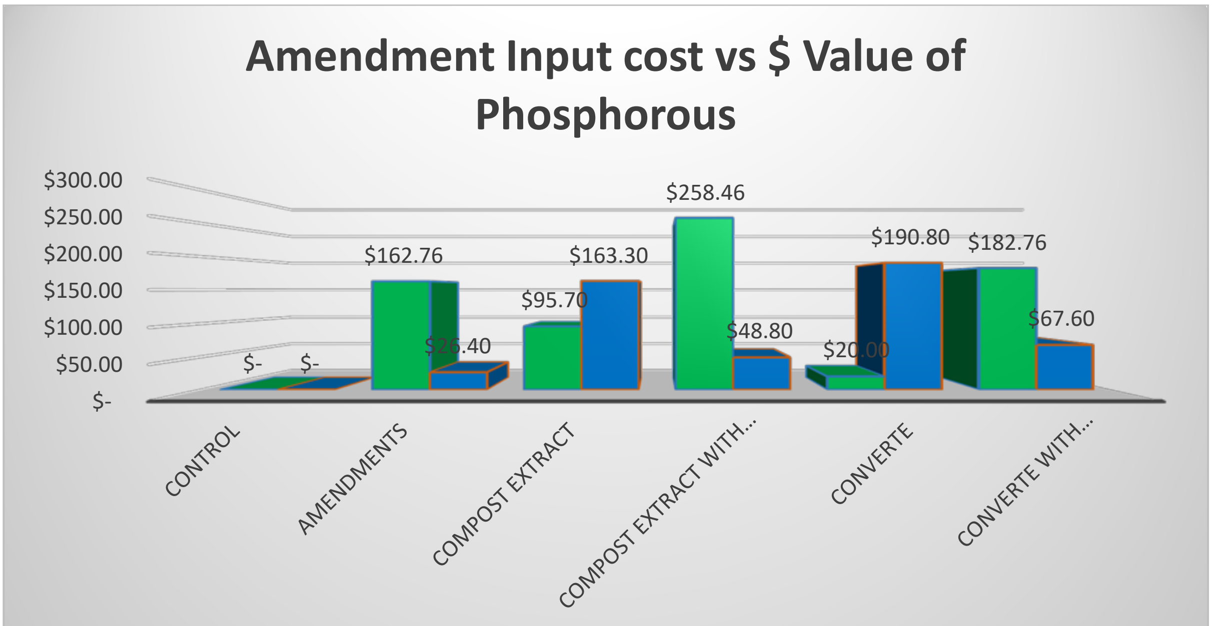
Analysis: Results show that microbe and microbe stimulant amendments alone released the highest levels of P after rewetting compared to control, probably due to the presence of greater soil biomass and activity. The plant nutrients plot released the lowest level of P, while microbes and microbe stimulants plus plant nutrients plots released much less than microbes and microbe stimulants alone. Because this data shows P release from microbe cells, the best results will come from the sample with the highest microbial count. Compost extract and Converte proved to be the most beneficial amendments. Further, the data indicates that plant nutrients tend to be less beneficial to soil biology.

Amendment Input Cost vs. Dollar Value of Phosphorous
Single Super is a well-known plant nutrient product offering 11% phosphorous (110kg/ton). It is applied to pastures regularly in our locality in the Northern Tablelands.

This graph compares:

- Cost of amendments (products applied) to each trial plot in $/hectare
- Value of phosphorous (P) found in each plot, in $/hectare, as though it had been applied as Single Super. $ value of P based on cost of Single Super as follows:
    - o Single Super costs $440/ton (110kg) delivered and spread on pasture. (July 2018, NSW price)
    - o $440/110kg = $4.00/kg phosphorous]

Results demonstrate the cost differential analysis (or lack thereof) in terms of plant-available P.



	Control	Amendments	Compost extract	Compost extract with amendments	Converte	Converte with amendments
Cost of inputs/hectare	$-	$162.76	$95.70	$258.46	$20.00	$182.76
$ value of phosphorous	$-	$26.40	$163.30	$48.80	$190.80	$67.60

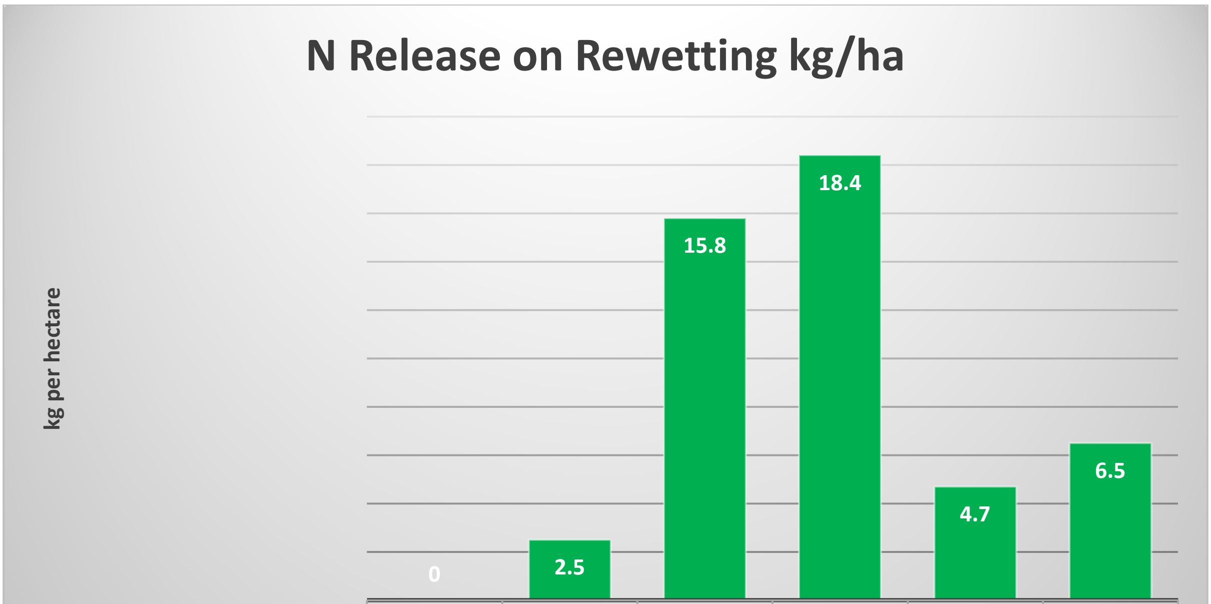
Cost of inputs/hectare and $ value P/hecatare

Figure 6: Amendment Input Cost vs $ Value of Phosphorous

Analysis: The plots treated with microbes and microbe stimulants alone released the greatest amount of plant-available P. When plant nutrients were added, measureable P decreased significantly. Results indicate that additional plant nutrients result in less biological activity and therefore, less available P. Converte alone had a cost of $20 and a phosphorous value of $190.80, giving the producer $170.80-worth of P more than control, based on the price of Single Super. Active microbes release locked up P to plants, and plant nutrients seem to suppress this activity.

Nitrogen Release on Rewetting of Soil

This test measures release of nitrogen (N) stored in microbial cells following a drying and then rewetting event, such as the end of a drought. It is measured in kilograms per hectare, with values representing kilograms of N more than what was released in the control plot. The nitrogen is plant-available.



	Control	Plant nutrients	Compost Extract	Converte	Compost extract + plant nutrients	Converte + plant nutrients
N release on rewetting kg/ha	0	2.5	15.8	18.4	4.7	6.5

Figure 7: Nitrogen Release on Rewetting results

Analysis: Results show that microbe and microbe stimulant amendments alone released the highest levels of N after rewetting. In fact, biology supplied roughly 1/3 to 1/2 the nitrogen usually applied to increase pasture growth on the Converte plot. The plant nutrients plot released the lowest level of N, while microbes and microbe stimulants plus plant nutrients plots released much less than microbes and microbe stimulants alone. Again, results suggest that plant nutrients suppress biological activity and biomass and therefore, the release of N stored in microbial cells after a rewetting event. To give an indication of the value of N release, nitrogen is usually applied at a rate of 30-50 kg/hectare on pastures.

Microbe Wise Results

Nutrient Accessibility
This test measures the presence of vesicular arbuscular mycorrhizae (VAM) which are the most abundant of a group of symbiotic fungi that live in plant roots. There is a strong correlation between the presence of VAM and nutrient accessibility. The plant roots exude carbon exudates, feeding the VAM and other soil biology. In exchange, VAM increases water and nutrient uptake by the plant.

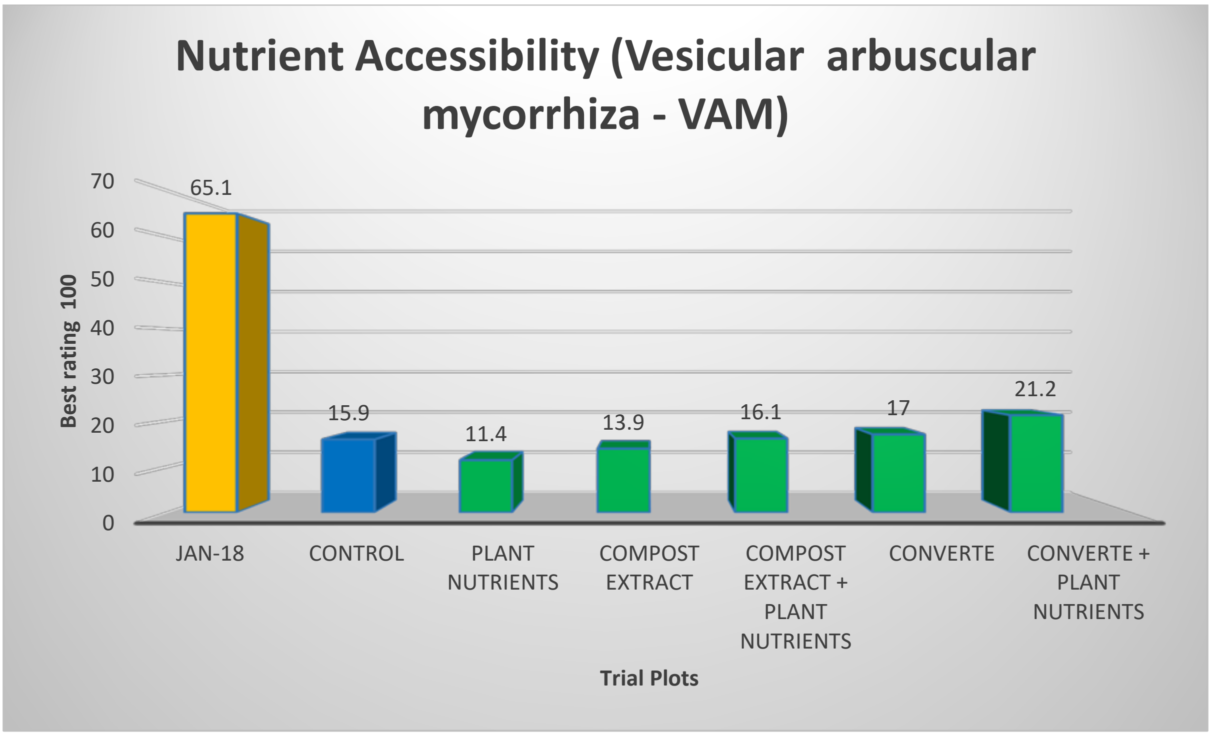


Figure 8: Nutrient Accessibility (Vesicular arbuscular mycorrhiza – VAM) results

Analysis: Test results indicate that plant nutrients alone and microbes alone decreased nutrient accessibility compared to control, while Converte (microbe stimulant) and Converte with plant nutrients increased nutrient accessibility. Results show a 33.3% improvement over control in the Converte with plant nutrient plot while plant nutrients alone were 28.3% less than control. The compost extract with plant nutrients plot was very similar to control. It appears that Converte stimulates VAM more than other amendments. Plant nutrients alone appear to suppress VAM.

Nutrient Solubilisation Rate

This test measures the rate at which nutrients are made available to plants.

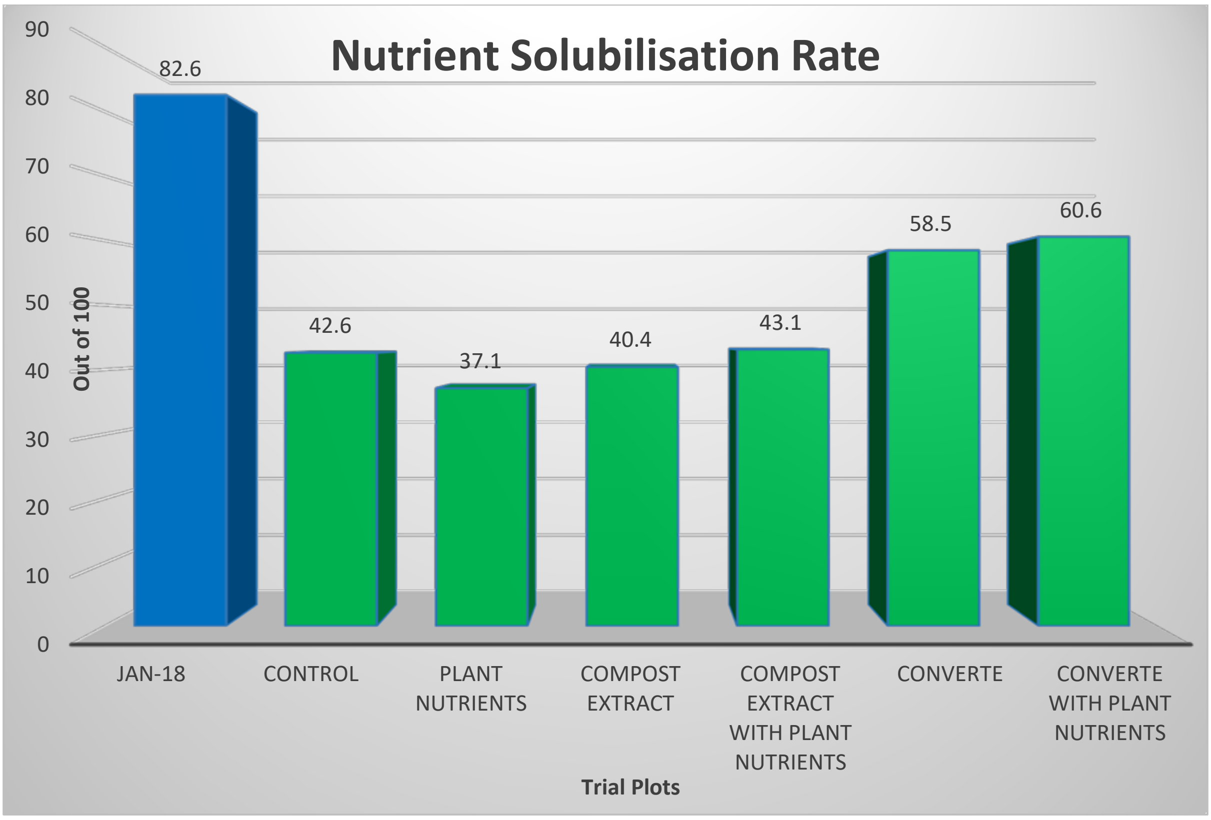


Figure 9: Nutrient Solubilisation Rate results

Analysis: Results show marked improvement in nutrient solubilisation rate in Converte (microbe stimulant) and Converte with plant nutrient plots. Converte alone was 37.3% better than control and Converte with plant nutrients was 42.5% better. The plant nutrient plot was 13% worse than control. Both compost tea extract and compost tea extract with plant nutrients showed almost no change compared to control. Converte plots may have performed best because Converte improves nutrient transfer (from plant-unavailable nutrients to plant-available nutrients) via living microbes.

Drought Resistance

This test measures relative drought resistance in soil based on the presence of gram positive bacteria and VAM. The rating is measured as best out of 100 based on lab values for a broad range of soils. There are many types of soils, and this test shows relative drought resistance compared to control.

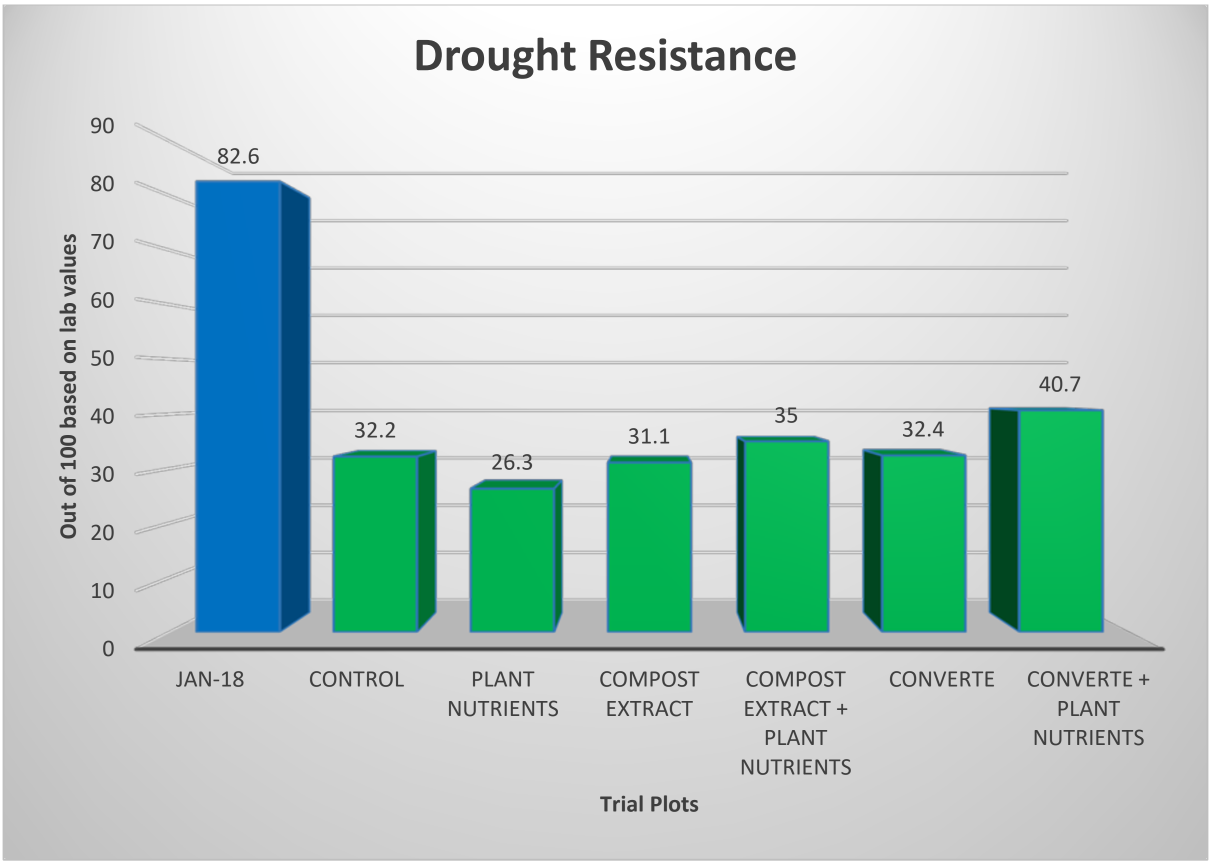


Figure 9: Drought Resistance results

Analysis: Results show that the plant nutrients plot was 20% worse than control, while Converte with plant nutrients was 26% better than control. It is interesting to note that Converte with plant nutrients performed better than Converte alone in this test. The other plots were very similar to control. It appears that plant nutrients alone actually suppress soil biology (in this case, gram positive bacteria and VAM.) It is also apparent that all values are significantly lower than the results taken in January 2018. This can likely be attributed to lower temperature and dry weather, both of which suppress soil biological activity. Soil biology shows itself as an obvious asset for times of drought.

Disease Resistance
This test measures disease resistance in the soil, calculated by the presence of pseudomonas (a species of gram-negative bacteria), vesicular arbuscular mycorrhiza fungi (VAM) and actinomycetes (a species of non-motile gram-positive bacteria.) The rating is measured as best out of 100 based on lab values for a broad range of soils. This test is best understood by comparing trial plot results against control.

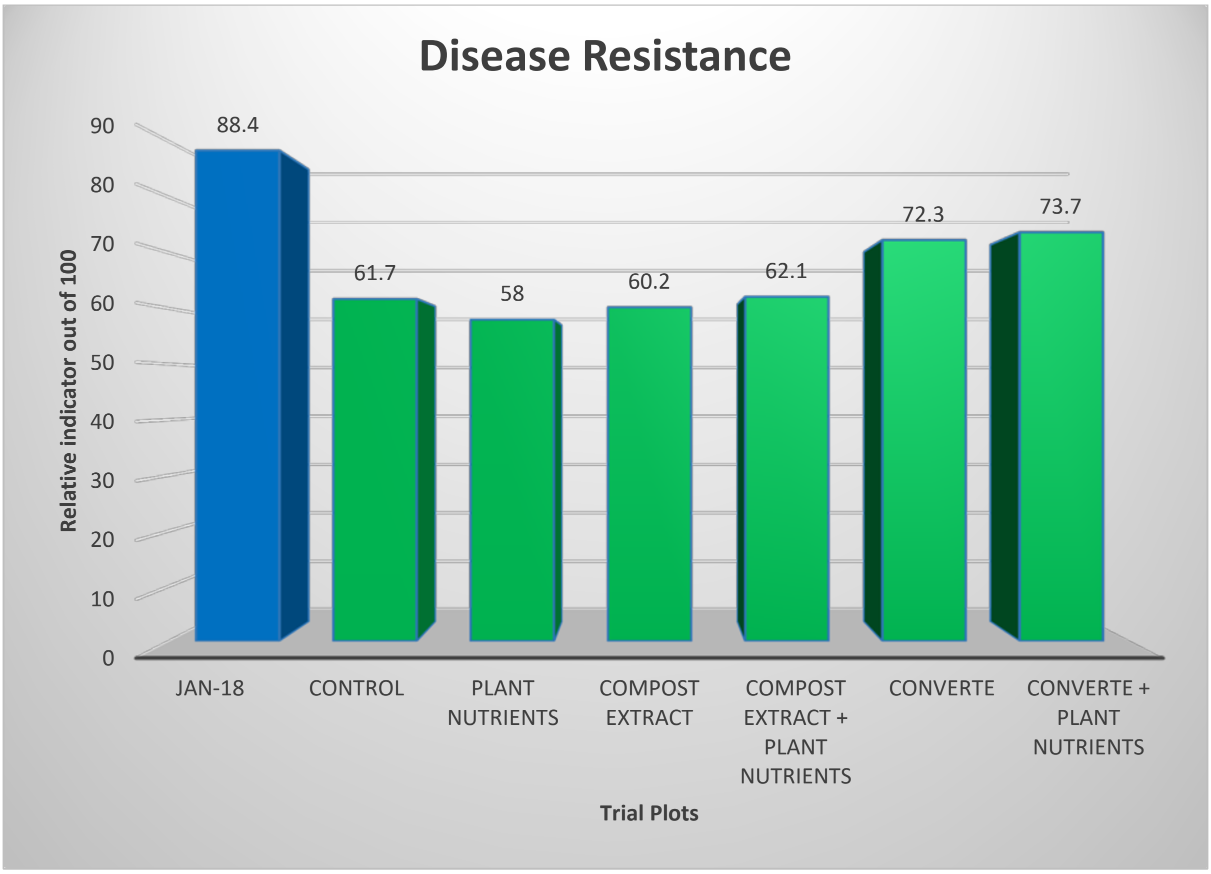


Figure 10: Disease Resistance results

Analysis: Converte and Converte with plant nutrients plots showed a significant advantage over control and all other trial plots. Plant nutrients alone were worse than control, as was compost tea extract alone. It appears that Converte stimulates the soil biology needed to confer disease resistance to plants, and that plant nutrients and compost tea extract seem to have little positive effect on disease-resistance. Both Converte plots were approximately 18% more disease-resistant than control.

Fungi to Bacteria Ratio
This test measures the ratio between fungi and bacteria in the soil. Graph numbers represent number of fungi, and bacteria are always 1. A higher fungi to bacteria ratio indicate a more sustainable system as nitrogen and carbon are better balanced.

The guide bar is intended for cropping soils. 2.3 is not a high ratio, as some cropping systems have ratios as high as 5:1.

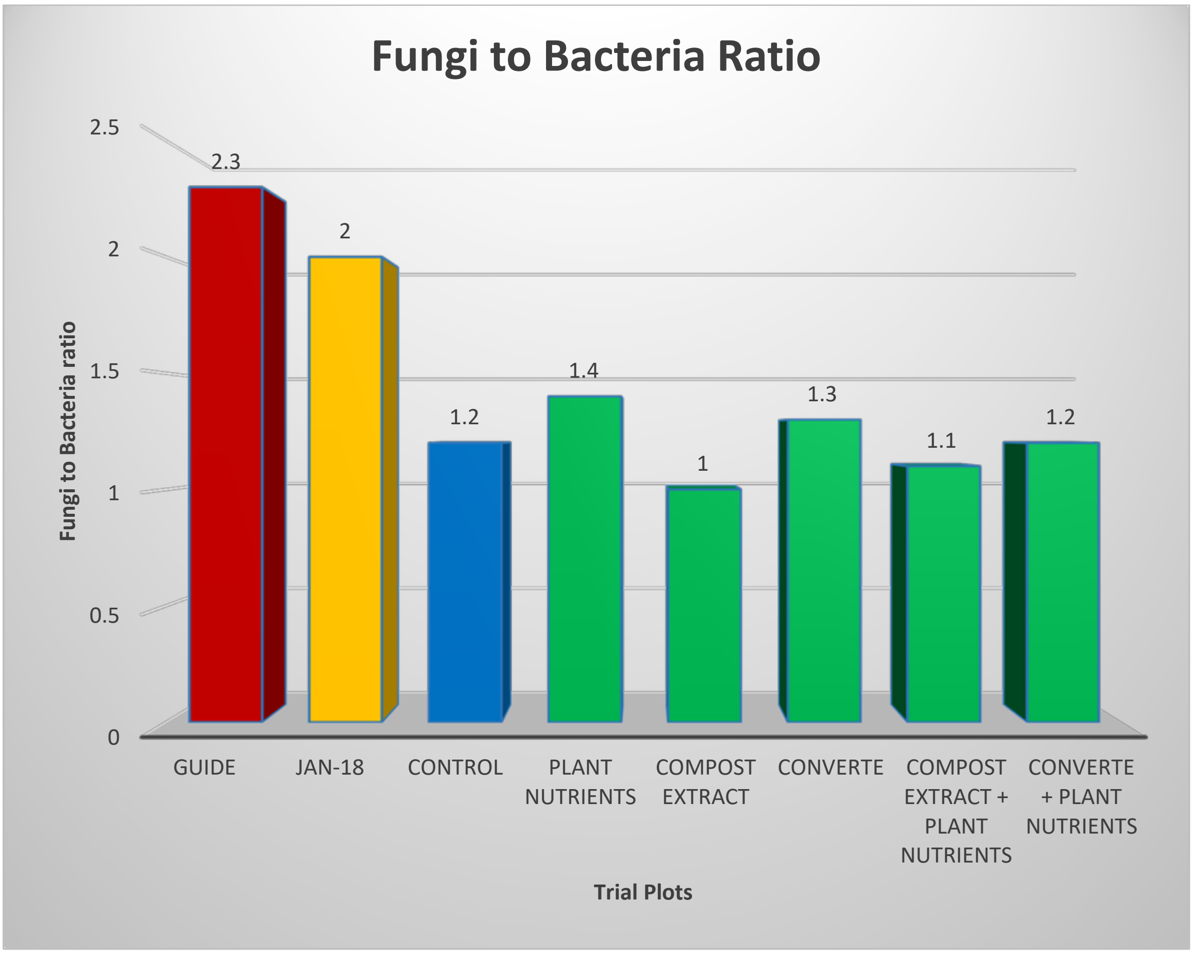


Figure 11: Fungi to Bacteria Ratio results

Analysis: Overall, fungi to bacteria ratios are quite low. Test results show a lower (worse) ratio in the plots treated with compost tea extract and compost tea extract with plant nutrients. Plant nutrients alone had the highest (best) ratio. All test plots, even control, had lower ratios than they had in January. We believe this is due to dry and cool conditions. Low ratios can also be an indication of past management practices (disturbed soils are known to have lower ratios.) It is interesting to note that in this test, plant nutrient plot performed better than either Converte or compost tea extract plots.

YLAD's Bio 500 TX-LP, the compost tea extract we used, is marketed by YLAD as fungal-dominant. We had expected this plot to have the best fungi to bacteria ratio, but it had the worst. Instead, it seems that the compost extract primarily affected the bacteria groups. Compost tea extract and other biological products normally have slower effects than fertilizers, so it will be interesting to see if the microbes and microbe stimulants have an accumulative effect in the next growing season.

Bacterial Stress

This test measures bacterial stress by looking at bacterial cell membranes exuding molecules when they are under harsh conditions. The results are based on standard lab values from a broad range of soils. A value of zero is desirable.

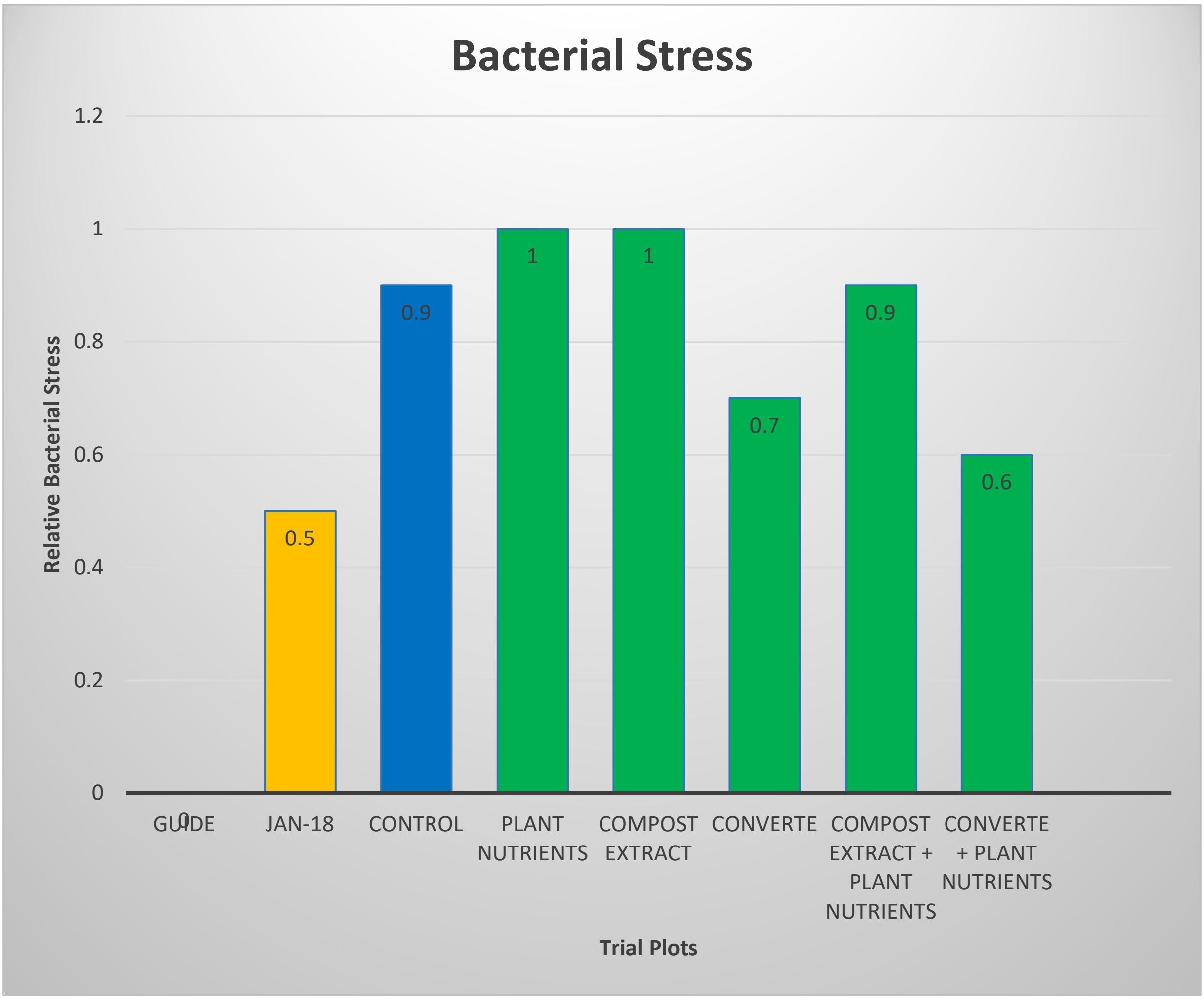
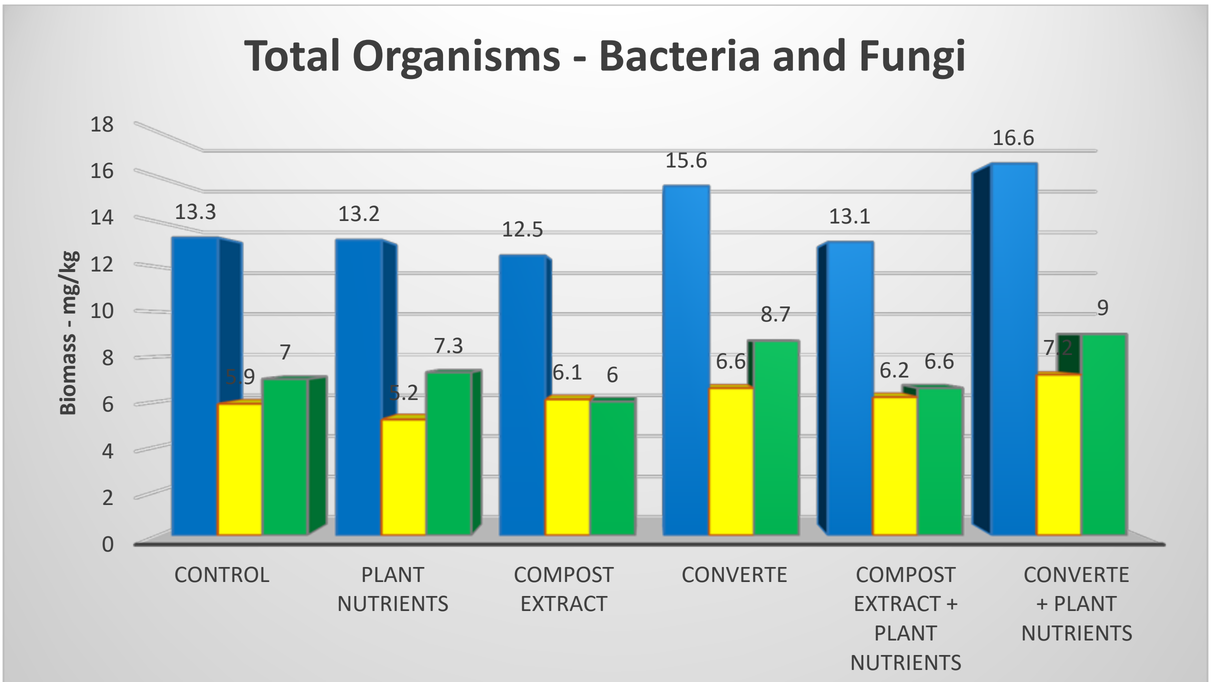


Figure 12: Bacterial Stress results

Analysis: Results show elevated bacterial stress levels in all trial plots compared to guide and pre-trial tests. We attribute this to dry and cool conditions. Both Converte and Converte with plant nutrients showed significantly less stress than other trial plots (20% and 30% less, respectively). While we cannot explain this, it indicates that Converte decreases bacterial stress more than other products. It is interesting to note that compost tea extract plots showed bacterial stress as high as control and plant nutrients plots.

Total Organisms (Bacteria and Fungi)
This test measures total bacterial and fungal biomass in soil. Higher levels exist in healthy soil. Lower levels are found when conditions are dry or cool. Microbial populations are increased by giving diverse carbon compounds as a food source and having adequate warmth and moisture.



	Control	Plant nutrients	Compost Extract	Converte	Compost extract + Plant nutrients	Converte + Plant nutrients
Total microorganisms	13.3	13.2	12.5	15.6	13.1	16.6
Total bacteria	5.9	5.2	6.1	6.6	6.2	7.2
Total fungi	7	7.3	6	8.7	6.6	9

Total microorganisms   Total bacteria   Total fungi

Figure 13: Total Organisms – Bacteria and Fungi results

Analysis: Converte and Converte with plant nutrients performed 18-20% better than the control and other plots. It appears that Converte stimulates soil biology more than other products. Compost tea extract and compost tea extract with plant nutrients had lower levels of fungi than control. This is surprising, as the compost tea extract is marketed as a fungal-dominant product. The results may indicate that fungi are more negatively affected than bacteria by cooler and drier conditions.

Pasture Biomass Production

Biomass Production by Weight

This graph shows plant biomass harvested from trial plots. Cuttings were taken after plants had reached maturity; the first cutting on 24 March, and the second cutting on 13 May.

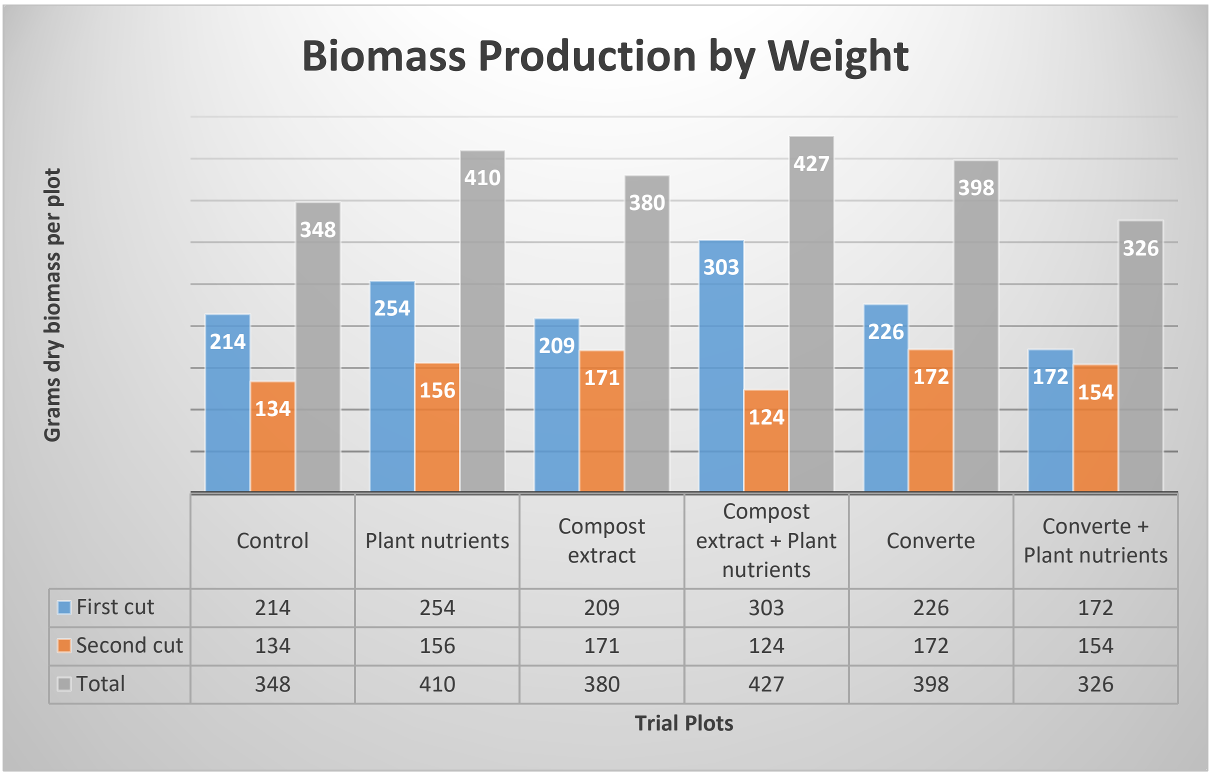


Figure 14: Biomass Production by Weight results

Analysis: Pasture biomass measurements show an interesting pattern, possibly because the trial ran for only 5 months (toward the end of the growing season) and only 2 cuttings.

Despite our effort to select a site with even plant distribution, plant density in each plot varied somewhat, affecting the biomass produced. However, there are some differences worth noting:

- First cut production % compared to control:
  - Plant nutrients – 18% more
  - Compost extract – 2.5% less
  - Compost extract with plant nutrients - 41.5% more
  - Converte - 5.6% more
  - Converte with plant nutrients – 20% less
- Second cut production compared to control:
  - Plant nutrients – 16.5% more
  - Compost extract – 27.6% more
  - Compost extract with plant nutrients - 7.5% less
  - Converte – 28.3% more
  - Converte with plant nutrients – 14% less

- Plant nutrients and compost tea extract with plant nutrients produced best on the first cutting but production decreased on the second cutting. This indicates that easily available nutrients can be used and depleted rapidly by plants, leaving little food for later on. We theorize that in the first growth period, abundant plant-available nutrients lead to rapid growth, but then plant nutrients were either used up or tied up in soil and second growth dropped in biomass production. However, Converte with plant nutrients did not do well in the first growth period despite having available plant nutrients. This may be related to variations in plant numbers in trial plots rather than actual plant growth.

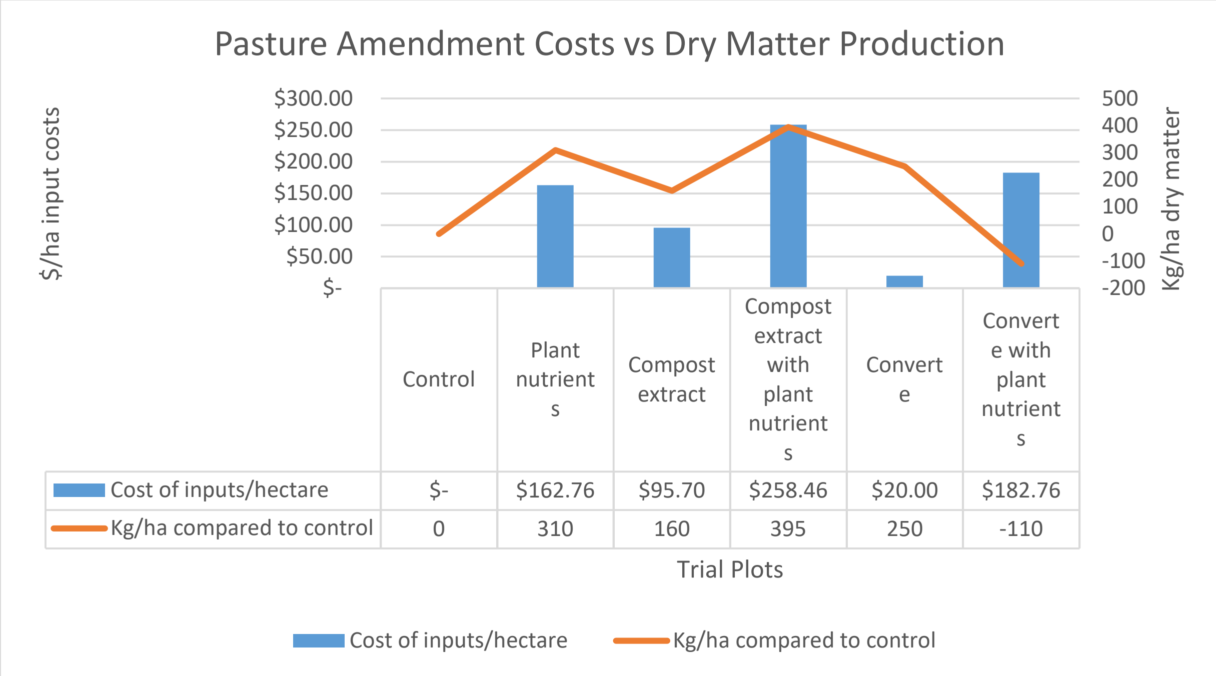
- Microbe and microbe stimulant amendments alone had the best results in the second biomass cutting. We theorize that the soil biology took some time to establish, making plant nutrients available more gradually. It will be interesting to see if this trend continues over time.

- It is important to note that from a financial perspective, the dollars spent on plant nutrients ($162.76/ha) was not returned in pasture growth when compared to control. Converte, costing $20.00/ha, represented good return on investment.

- This being noted, results are not conclusive. We plan to continue this investigation for another 6 to 12 months to observe if any plot has a measureable advantage in biomass production.

Pasture Amendment Costs vs Dry Matter Production

This chart shows pasture biomass produced in each trial plot in kg/hectare graphed against the $value of amendments applied to trial plots measured in $/hectare.



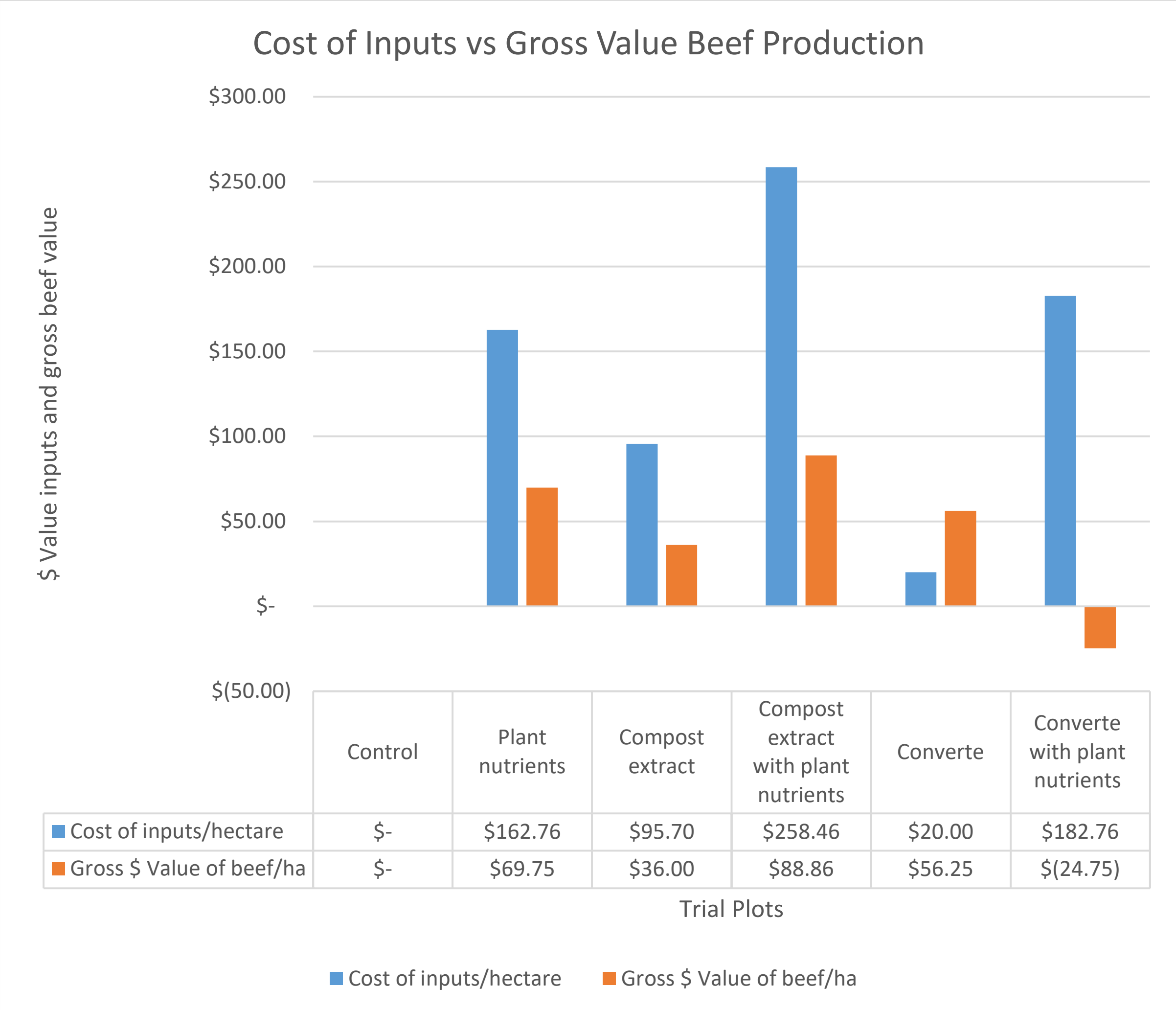
	Control	Plant nutrients	Compost extract	Compost extract with plant nutrients	Converte	Converte with plant nutrients
Cost of inputs/hectare	$-	$162.76	$95.70	$258.46	$20.00	$182.76
Kg/ha compared to control	0	310	160	395	250	-110

Figure 15: Pasture Amendment Costs vs Dry Matter Production results

Analysis: This test is important because the cost of increasing production is equally important as the production itself for a land manager or farmer. In this case, Converte produced 250 kg/ha dry matter more than control, and cost $20.00. That equates to $0.08/kg dry matter. Converte with plant nutrients produced 110 kg less than control and was the worst performer. Compost tea extract produced 160 kg/ha dry matter and cost $95.70 which is $0.59/kg. Plant nutrients cost $0.52/kg dry matter. In this trial, increasing production over control cost 6 times less using Converte than any other product. Some of these results can be attributed to slight variations in plant densities in each plot, and further monitoring will give more accurate data.

Cost of Inputs vs Gross Value Beef Production

This chart shows cost of inputs per hectare, against the gross value of beef produced (theoretically) from the grass grown per hectare over the control plot. Amount of beef produced is based on the long term average live weight gain for cattle grazing on our property which is 0.75 kg/10 kg dry matter consumed. While this method of calculating weight gained from dry matter is not very accurate, it is widely used in the grazing industry.



	Control	Plant nutrients	Compost extract	Compost extract with plant nutrients	Converte	Converte with plant nutrients
Cost of inputs/hectare	$-	$162.76	$95.70	$258.46	$20.00	$182.76
Gross $ Value of beef/ha	$-	$69.75	$36.00	$88.86	$56.25	$(24.75)

Figure 16: Cost of Inputs vs Gross Value Beef Production results

Analysis: The results show that during the 5 months of the trial, only the Converte alone plot produced a higher dollar value of beef than the cost of the amendment applied. It is important to remember that 5 months is a short time in a pasture and we will continue to monitor how each plot responds in the next growing season.

Final Analysis

ActivityWise Soil Test

This test was run twice by Microbiology Labs Australia on the post-trial soil sample sent in May. The first test used a 1-day technique, which was the same methodology as the pre-trial January test. The lab director Dr. Maria Manjarrez decided to run the post-trial test again using a 3-day technique for more accurate results. It is the second post-trial test that we have used in analysis. Therefore, we have not compared pre- and post-trial results for ActivityWise test.

Results of this test show a high level of microbial activity compared to lab guide value. (However, lab guide value is based on cropping soils, known to be poor. We requested a guide value for pastures, but none has been calculated to date. The lab advised that pasture values would be higher than cropping soil values.)

Test results showed the following:

- Significantly more microbial activity, biomass and respiration over control in plots treated with either compost tea extract (25% more) or Converte alone (29% more).
- Plant nutrients plots were 4% better than control
- Plots treated with microbes or microbe stimulants plus plant nutrients showed a moderate rise in values over control (7-8%).
- There was a substantial release of P after rewetting in both Converte and compost tea extract plots. This represents a significant amount of this important crop nutrient, and an excellent return on investment when compared to buying phosphorous as Single Super.
- Nitrogen release on rewetting was highest in Converte and compost tea extract plots, while all other plots were similar to control.

This test shows a clear benefit of compost tea extract and Converte. Adding plant nutrient amendments to either biological product seemed to suppress soil biological activity and biomass, and plant nutrients alone showed almost no improvement over control.

Why this result? Plant root exudates are essential for soil biology to thrive. When chemical nutrients are easily available to plants, the plants have no need for a symbiotic relationship with soil biology. The plants conserve their energy and do not provide root exudates, resulting in fewer soil microbes and less microbial activity.

These findings have important implications for our farm and for land managers generally and even for the general public. Chemical nutrient amendments, or conventional fertilizers, appear to suppress the very mechanism that nature uses to transfer nutrients from soil to plants. This has many effects, including decreased plant nutrient density, decreased water use efficiency, and a decrease in plants' access to micronutrients not included in the fertilizer. In addition, chemical nutrient fertilizing can be very expensive. Evidence is growing that food grown in healthy, biologically active soils is more nutrient-dense and has the correct balance of micronutrients essential for good health.

The microbe stimulant, Converte, had the greatest positive impact on soil biology in this trial. It was also the least expensive. It represents best value for money for the primary producer. This testing needs to be repeated in different soil types and over a longer time period to assess varying response.

MicrobeWise Soil Test

Our pre-treatment MicrobeWise Soil Evaluation (MWSE) in January showed much higher values compared to results of tests in May. The second test was taken in late autumn and we were experiencing dry and cooler conditions. These factors likely decreased the microbe population, and caused them stress, as results show. However, there was still a difference between trial plots that is worth noting.

MWSE measures a range of microbial markers including nutrient accessibility, nutrient solubilization rate, drought resistance, disease resistance and residue breakdown rate. This test also measures microbial diversity, fungi to bacterial ratio, bacterial stress, and total bacterial and fungal organisms.

- Converte and Converte with plant nutrients had the best overall results in this test. Compost extract and compost extract with plant nutrients consistently had weaker results. It seems that Converte confers a benefit to soil biology that compost tea extract does not.
- The Converte plot showed 20-30 % less bacterial stress than control. (Other plots were quite similar to control.)
- The Converte plot showed 18% better disease resistance than control. (Other plots were similar to control.)
- The plant nutrients plot showed 20% less drought resistance than control; Converte with plant nutrients was 26% more drought resistant than control.
- Converte with plant nutrients showed 33% better nutrient accessibility than control; the plant nutrients plat had 28% less nutrient accessibility than control.
- Converte with and without plant nutrients had approximately 40% better nutrient solubilization than control, while the plant nutrients plot had 13% less nutrient solubilization than control.

When taking plot amendment costs into account, Converte will deliver most benefit per dollar spent.

Pasture Biomass Analysis

Plant nutrient and Compost extract with plant nutrient plots produced most biomass in 1st cut while Compost tea extract and Converte produced more biomass in second cut. These results support our thought that readily available plant nutrients will cause rapid growth at first, but then when nutrients are used up or locked up in soil growth slows. Biology, which helps make nutrients available to plants naturally, takes longer to develop and work in the soil, explaining the results of the second cut.

However, pasture biomass results were inconclusive. The following facts contribute to this.

- Trial plots were small, so any variation in plant distribution and plant numbers had a significant effect on results.
- Trial duration was relatively short, with only two pasture biomass harvests.
- Note: We plan to continue this investigation for another 6 – 12 months to observe if any plot has a measureable increase in biomass production over other plots, or shows a trend of increasing or decreasing production over time.
    - We will monitor each plot's biomass production both against the other plots and against itself. Over the next year, we expect a trend to show in each plot.
    - To further evaluate the quality of biomass produced, we will measure the Brix level of each plot. Brix measures sugar content of plant sap and is an indication of mineral content of plants, and therefore nutrient availability. The higher the Brix level, the healthier the plant and the healthier the soil it is growing in. Higher Brix levels in plants have also been shown to improve livestock performance per unit grazed.
    - Microbiology Laboratories Australia has kindly agreed to help pay for further biological soil analysis in January 2019 so that the investigation can continue for a full year.

Reflections

In reviewing this investigation, we learned the following:

- Trial plots should have been larger or replicated to reduce variability.
- A longer trial time (at least 12 months) will yield more accurate data.
- We should have measured Brix levels from the outset.
- We should have measured microbial levels and microbial activity in all trial plots to reduce variability.
- It would be a better investigation if plots were located on varying soil types and in various locations. Cost of soil testing was prohibitive.
- A second chemical soil analysis at the end of the trial would provide additional insight, especially regarding the levels of nutrients in soil that were shown to be deficient in pre-trial testing. However, the cost of testing was prohibitive.
- Comparing soil biology test results obtained in January 2018 with testing we will do in January 2019 will give a more accurate result, being the same time of year and temperature as pre-trial testing.

Conclusion

The results of our soil biology trial differed slightly from our hypothesis which stated that compost tea extract with plant nutrients would out-perform all other plot amendments. We discovered that plant nutrients (fertilizers) seemed to have a suppressing effect on soil biology and that microbes and microbe stimulants measurably increased soil biological mass, activity and phosphorous and nitrogen availability. Converte especially increased drought and disease resistance, and increased nutrient accessibility and nutrient solubilisation which would be of great benefit to farmers suffering in the current drought.

Pasture biomass production results showed more growth response from plant nutrients and compost tea extract with plant nutrients in the first cutting, while Converte and compost tea extract alone produced more biomass on the second cutting compared to control. This correlates with plant nutrients being available immediately while soil biology took time to establish and have an effect on nutrient availability and thus plant growth. The microbe and microbe stimulant products performed best, both ecologically and financially, when compared against dollars invested.

In conclusion, trial results show that both of the microbe and microbe stimulant products trialed measurably increase soil biological activity and available P and N, and that active, healthy soil biology is likely a key to improved soil health and pasture production.

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Appendices

Appendix A: Maths, log book and photos

Appendix B: Laboratory Test Results