Regenerative Agriculture

A Soil Health Focus

A report for

NUFFIELD AUSTRALIA FARMING SCHOLARS

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Executive Summary

Regenerative agriculture is a holistic, systematic approach to farming which mimics natural processes. It is a system aimed at optimising soil and plant health and increasing soil carbon levels. Regenerative agriculture encompasses the principles of permaculture, organic, biodynamic and biological farm practices.

The management of agricultural soils to improve their capacity to sequester and store carbon as stable humus provides significant benefits in terms of soil structure, water-holding capacity and nutrient status, helping to improve farm productivity and profitability. Restoring the carbon levels of the planets agricultural soils provides a short-term solution to climate change whilst improving the resilience and productivity of our farming systems.

Adoption of regenerative agriculture requires a paradigm shift by farmers. Management practices require a focus on maximising the photosynthetic capacity of plants and address soil mineral and microbial balance. Soil biology must be actively managed to maintain and improve soil health and fertility.

Farmers are utilising innovative methods of microbial reproduction, fertiliser production and grazing management to regenerate and reactivate soil biology and enhance plant and animal nutrition.

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Foreword

My wife Kylie and I operate a family farming business on 800ha at Tantanoola in the Lower South East of South Australia, with the support and encouragement of my parents, Peter and Beth. Like many farms in the area, our land is spread over several different blocks with soils ranging from black cracking clays and peats to red and grey sandy loams.

The business is focussed on grazing. Enterprises include a self-replacing composite ewe flock producing prime lambs, cattle trading and more recently pastured free-range egg production. Good quality underground water allows us to utilise centre pivot irrigation for grazing and fodder production and opportunity cropping is utilised in our pasture improvement program.

I joined the family farming business after completing studies at Roseworthy Agricultural College. We farmed "conventionally" for a number of years before I began to question the economics and agronomics of applying synthetic fertiliser, chemicals and re-sowing pastures year after year with little improvement in profit, weed and disease pressure or pasture persistence. I attended Resource Consulting Services "Grazing for Profit" school and participated in their "Executive Link" program where I was introduced to some of the concepts of regenerative farming by consultants such as Dr Phil Wheeler and Jerry Brunetti. This information challenged our current farming practices and lead to experimentation with biological inputs.

The change to biological inputs has seen the incorporation of organic fertilisers, composts and foliar nutrient sprays such as humates, seaweed and fish concentrate into our fertility program. These changes were made in an attempt to reduce the use of synthetic fertilisers, address some of the mineral imbalances in our soils and improve soil, plant and livestock health. Sourcing cost-effective, quality biological inputs has been difficult with many suppliers claiming they have the next 'biological silver bullet'. The use of biological inputs was pursued with the aim of reducing costs, however we just seemed to swap our 'chemical bill' for our 'biological bill'.

My interest in a Nuffield Scholarship developed from a desire to investigate what simple, cost effective biological methods farmers were using to improve soil health and the need for the development of systems to allow farmers to confidently adopt regenerative farming practices.

During the scholarship I travelled to New Zealand, USA, Canada, UK, Brazil, Mexico, Costa Rica and Ecuador, visiting a diverse range of enterprises including avocadoes, kiwifruit, bananas, citrus, vegetables, broad acre cropping and grazing.

The highlight of my Nuffield travels was joining a group of Australian farmers on a Latin American study tour investigating on farm fertiliser and microbe production.

Figure 1. Mas Humus Latin American Study Tour, September 2013. Source: T. Morales

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I would like to acknowledge the following people for their support whilst I have undertaken this scholarship - a once in a lifetime opportunity.

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Abbreviations

EM - Effective Microbes

GHG – Green House Gases

PPM – Parts Per Million

SOC – Soil Organic Carbon

SOM – Soil Organic Matter

UNCTAD – United Nations Conference on Trade and Development

Objectives

This report aims to:

- Outline the importance of soil health with regard to improving agricultural production and soil carbon sequestration.
- Gain an understanding of soil health parameters and their link to plant and animal health.
- Investigate simple, on-farm methods of achieving soil mineral and microbial balance.

Chapter 1: Introduction

"*Regenerative organic agriculture improves the resources it uses, rather than destroying or depleting them. It is a holistic systems approach to agriculture that encourages continual on farm innovation for environmental, social, economic and spiritual wellbeing"*

Rodale Institute (2014)

Regenerative agriculture is a holistic, systematic approach to farming designed to build soil health, with on-farm carbon sequestration being a management priority. It is an approach to farm production that respects natural processes and strives to achieve a balanced relationship between the physical, chemical and biological aspects of the soil. These practices focus on soil health and increasing soil carbon levels. Central to regenerative farming is the aim to improve the land, using technologies that regenerate the soil and the environment. Regenerative Agriculture leads to healthy soil, capable of producing high quality nutrient dense food.

Regenerative management practices take advantage of an ecosystems natural tendency to regenerate after disturbance and are characterised by closed nutrient loops, a tendency towards more perennial plants and greater biological diversity. These practices promote an increase in organic soil carbon levels and offer the added benefits of increased productivity and greater resilience on farms. Improved soil carbon levels result in increased microbial activity, improved water-holding capacity, more effective nutrient cycling and improved farm profitability (Rodale, 2014).

Adoption of regenerative practices such as conservation tillage, cover cropping, enhanced crop rotations, residue retention, pasture cropping and planned grazing are all focussed on maximising soil cover and maintaining actively growing roots to support soil microbes. These are recommended management practices as they build soil organic matter, minimise soil disturbance, reduce erosion and contribute to soil carbon sequestration and soil health.

The September 2013 United Nations Conference on Trade and Development (UNCTAD) report, "Wake up before it is too late", calls for a fundamental transformation of agriculture and a return to proven sustainable farming practices. Strategies advocated within the report include closed nutrient cycles aimed at increasing soil carbon content, sustainable grassland management, optimization of fertilizer use (both organic and inorganic) and reduced food chain wastage.

The fundamental changes to agricultural practices called for by the UNCTAD are not new or experimental - these practices form the basis of biological, regenerative, organic and biodynamic farming methods.

1.1 Soil Carbon Sequestration and Climate Change

It is estimated that agricultural soils have lost 30 to 75 percent of their original soil organic carbon (SOC) since mankind began farming (Lal et al, 2007). As a result, 136 Gigatonnes of carbon has been released from the world's soils into the earth's atmosphere (Lal, 2004). Carbon dioxide levels in the atmosphere are currently around 400 ppm, with scientists estimating that the atmospheric carbon dioxide level must be reduced to about 350 ppm to avoid catastrophic climate change (Kittredge, 2015).

Global discussions have focussed on the reduction of carbon emissions as the main strategy to prevent further increases in Green House Gases (GHG). However, an increasing number of agricultural scientists are promoting soil carbon sequestration as a simple strategy that can permanently store sequestered atmospheric carbon, whilst improving soil health and agricultural productivity.

The Rodale Institute White Paper, "Regenerative Organic Agriculture and Climate Change", 2014, states that on-farm soil carbon sequestration can potentially sequester all of our current annual global GHG emissions. Furthermore, Lal, (2004) indicates that improved management of agricultural land utilising inexpensive soil building practices can reduce GHG emissions and act as a direct carbon dioxide sink, increasing SOC and improving agronomic productivity.

The management of farm soils to improve their capacity to sequester and store carbon as stable humus provides significant benefits in terms of soil structure, water-holding capacity and nutrient status, helping to improve farm productivity and profitability (Jones, n.d.). Restoring the carbon levels of the planets agricultural soils provides a short-term solution to climate change whilst improving the resilience and productivity of our farming systems.

Recently the French Government launched the "4 per 1000: Soils for Food Security and Climate" initiative, with the aim of demonstrating that agriculture and agricultural soils in particular, can play a crucial role where food security and climate change are concerned. According to the French Agriculture Ministry, a 0.4% annual growth rate in soil carbon content would make it possible to stop the present increase in atmospheric carbon dioxide and limit global temperature increase. The initiative intends to demonstrate that even a small increase in carbon in agricultural soils (particularly in grasslands, pastures and forests) is crucial to improve soil fertility and agricultural production whilst helping to achieve the long term objective of limiting the global temperature increase to 1.5 to 2 degrees Celsius.

1.2 Liquid Carbon Pathway

Carbon enters the soil through the exudation of sugars (glucose), amino acids and lipids, produced during photosynthesis, from actively growing plant roots. This flow of carbon into the soil stimulates the production of humus, the organic component of soil that stores carbon and provides the basis for soil fertility (Schwartz, 2013).

Approximately 20 to 40 percent of the carbon a plant fixes through photosynthesis is transferred into the soil immediately surrounding its roots to encourage symbiotic relationships with soil microorganisms. Jones (2008) refers to this flow of sugars into the soil from plant roots as the "liquid carbon pathway", and likens it to a two-way pump.

Water, minerals and other substances the plant requires for growth flow up from the soil via the microbial bridge formed between the plant roots and soil microbes. Conversely, soluble carbon (dissolved organic carbon) flows down into the soil, via the roots, to feed soil organisms (Jones, 2015).

1.3 Photosynthesis and Soil Organic Matter (SOM)

Photosynthesis is the single most important process in nature and regenerative farming depends on the optimisation of photosynthesis and the efficient "harvesting" of carbon from the atmosphere by green plants. Sunlight is the ultimate energy source for all agricultural systems, whilst carbon is the driver of soil health and function (Jones, 2007, Melendrez, 2014).

New soil research emphasises the need to actively manage soil biology to maintain and improve SOM. University of New Hampshire scientists have discovered evidence that microbial pathways are the chief source of the organic matter found in stable soil carbon pools. The research by Kallenbach et.al. (2016), demonstrates that SOM is formed by microbial digestion of carbon from roots and root exudates. Furthermore, distinct microbial communities drive SOM increases and SOM accumulation is higher in soils with greater fungal abundance. Prior to this research, SOM formation had historically been depicted as a function of plant inputs to the soil such as lignin and long-chain lipids. This research highlights the importance of optimising photosynthesis to provide the soluble carbon that soil biology depends on for a food source and that ultimately results in increased SOM and soil health.

The author noted during his research that many of the farmers applying regenerative farming practices were endeavouring to promote and manage biology in their soil. Microbial food sources such as humates, fulvic acid and molasses were being applied as part of foliar spray programs to encourage increased microbial populations. Farmers were also "brewing" indigenous and commercially produced microbes and applying these to both soil and plants to aid in the decomposition of crop residue, disease suppression and nutrient availability.

Chapter 2: Minerals, Microbes and Organic Matter

2.1 Minerals

Mineral management in a regenerative farming system focuses on the balance of macro and micronutrients in the soil. Optimum mineral levels within the soil are commonly based on the research of soil scientist William. A. Albrecht. Albrecht substantiated that declining soil fertility, identified by a lack of organic matter, was due to an imbalance of major and trace elements. According to Albrecht, cations within the soil need to be in a particular ratio to enable plants to have ready access to them.

US soil consultant Neal Kinsey, in his book "Hands on Agronomy" (1993), defines Albrecht's ideal ratios of soil cations as:

- 60-70% Calcium.
- 10-20% Magnesium.
- 3-5% Potassium.
- 1% Sodium.
- 10-15% Hydrogen.
- 2-4% other cations.

Leading biological consultants focus on six key ratios to achieve soil mineral balance:

1. Calcium to Magnesium ratio of 7:1 (for heavy soil) based on base saturation.
2. Magnesium to Potassium ratio of 1:1 in parts per million (ppm).
3. Phosphorus to Zinc ratio of 10:1 (in ppm).
4. Sulphur to Phosphorus ratio of 1:1 (in ppm).
5. Potassium always greater than Sodium based on base saturation.
6. Iron to Manganese ratio a maximum of 2:1 (in ppm).

The application of minerals to the soil to achieve the ideal ratios in high cation exchange capacity soils is often not economic. Foliar applications of minerals that have been identified as being deficient in the plant through sap or leaf analysis provide an alternative method to optimise plant health. Foliar spraying of nutrients is 8 to 20 times more efficient than soil application and eliminates the issues of mineral tie up in the soil and leaching (Sait, 2014).

The importance of the various mineral elements to plant health is emphasised by the concept of a ‘Biochemical Sequence of Nutrition in Plants’ or hierarchy of importance of minerals required for optimum plant growth (Lovel, 2014). Minerals early in the sequence must be present and functioning before minerals occurring later in the sequence influence plant growth. The Biochemical sequence can help to determine key deficiencies in the soil and the earlier deficiencies occur in the sequence the greater effect on plant growth. Nitrogen, phosphorus and potassium are listed later in this sequence, with the focus being initially directed to sulphur, boron, silicon and calcium.

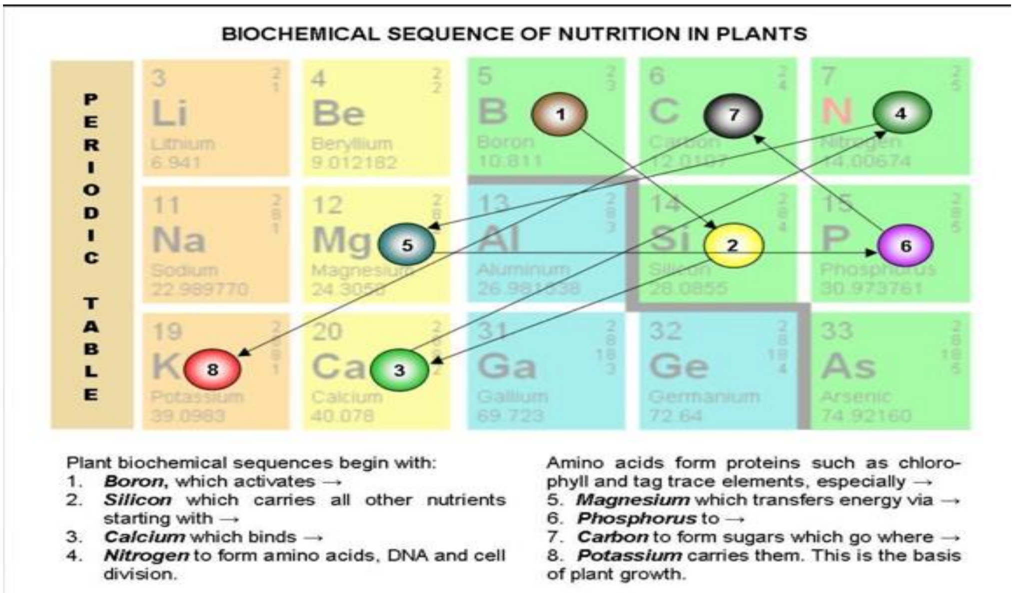

Figure 2: Hugh Lovel, Quantum Agriculture

The author’s research has led him to believe that a narrow focus on nitrogen, phosphorus and potassium fertility can be a limiting factor in maximising plant production. An understanding of the various mineral interactions and physiological processes that form the basis of plant growth is essential to develop a fertility program which addresses all of a plants nutritional needs.

2.2 Microbes

Soil microbes are the “bridge” between minerals and plants. Eighty five to ninety percent of the nutrients plants require for growth are acquired via the “microbial bridge” formed whereby root exudates provide energy to soil microbes in exchange for minerals and trace elements otherwise unavailable to the plant (Jones, 2015). Healthy plants, which have an energy surplus, can release 60 to 70 percent of their total energy production into the soil as exudates (Marschner, 1986).

The dominance of either bacteria or fungi within the rhizosphere results in two types of microbial digestion of root exudates. Bacterial digestion of the exudates results in the extraction of minerals from the soil matrix (mineralisation), as the bacteria use the minerals to build their own cells. The bacteria then become the primary food source for other microbes, with the microbial metabolites released during this process being utilised by plants (Kempf, 2016). Fungal digestion of plant exudates (especially lipids) leads to the formation of complex, long chain, stable humic substances, in a process known as humification, a key component of carbon sequestration and soil creation.

Ninety percent of the planets terrestrial plants form a symbiotic mycorrhizal association whereby fungus colonises their roots. This association provides the fungi with access to the plants soluble carbon while the plant benefits from improved mineral and water absorption capabilities due to the large surface area of the fungal hyphae (Leake et al. 2004). Mycorrhizal mycelium can constitute up to 20 to 30 percent of the microbial biomass of soil and research findings demonstrate there are correlations between increased soil carbon levels and the abundance of mycorrhizal fungi within the soil. However, excessive soil disturbance and the application of phosphate and nitrogen fertilisers suppress mycorrhizal colonisation of plant roots.

Arbuscular Mycorrhizal fungi (AMF) are particularly important in allowing plants access to immobile minerals like phosphorus, zinc and potassium, whilst their hyphae exude biochemicals that stimulate the plant's immune system. AMF also secrete a protein called glomalin, which is recognised as a key stimulant in rebuilding soil humus levels (Sait, 2014). Research indicates that mycorrhizal fungi and glomalin are largely responsible for creating persistent, stable soil aggregates that protect soil carbon from being lost as carbon dioxide, with glomalin remaining in the soil as a stable form of organic carbon for decades (Kell, 2011). Commercially produced cultures of AMF spores are available to allow farmers to reintroduce these important fungi to their soils.

Soil biology indexes have been developed to measure biological fertility (Solvita 24-hour carbon dioxide Burst test). These measurements of soil biological function are related to respiration rate of carbon dioxide from the soil and give an indication of the mass of microbes in the soil and the potential nutrient supply to plants. A significant connection between soil respiration and plant photosynthesis has been demonstrated, highlighting the contribution of biology to plant productivity (Brinton, 2015).

There are several biological pathways that directly contribute to plant productivity:

1. Mineralisation of organic nitrogen to nitrates by microbial activity.
2. Extraction and buffering of the soil solution using carbonic acid from microbial activity.
3. Soil aggregate formation.
4. Supplying plants with carbon dioxide for photosynthetic assimilation - plants obtain the carbon dioxide they need principally from soil respiration (Brinton, 2015).

A range of ideas was encountered during this investigation of microbe and mineral management with regard to the priority in which each should be addressed. New Zealand biological consultant Bill Quinn advocates focussing on the microbial diversity in the soil. He suggests that soil biology would cycle minerals and make them available to plants without the need to correct any mineral imbalances (Bill Quinn, Pers. Comm., 2014).

Whilst in the United States the author met with biological consultant and organic farmer Gary Zimmer. He advocates the use of both cover crops and soil mineral balance to maximise the potential of his intensively grown corn, soy and sweet corn crops. Zimmer likens the soil to a cow's gut that must be fed correctly and emphasises mineral balance in achieving the optimum conditions for soil microbes to flourish. Gary maintains that soil mineral deficiencies need to be addressed before microbial balance can be achieved (Gary Zimmer, Pers. Comm., 2014).

Zimmer favours a bacterially dominant soil for maximising crop production and has noted a small increase in SOM (approximately one percent) over the last 20 years. He states that bacteria provide a nitrogen source for plants by digesting sugars in the rhizosphere and releasing plant available nitrogen, whilst fungi are more involved in cellulose digestion. Raw sugar is being used as a part of some fertiliser programs recommended by Zimmer for the purpose of feeding soil biology and allowing a crop to fulfil it's genetic potential.

2.3 Organic Matter

Adequate levels of organic matter and a functional carbon cycle are essential for soil health. A lack of humus and biology significantly reduce the soils water holding capacity and ability to release nutrients, resulting in lower production.

There are three primary means by which soil carbon content can be increased.

1. Importing carbon through the addition of humates or leonardite and their derivatives such as fulvic and humic acids.
2. Carbon generation or capture through the management and decomposition of crop residues, composting and cover crops.
3. Carbon induction by optimising the carbon cycle and photosynthesis (Kempf, 2016).

Induction has the greatest potential to build stable humic substances, stimulate biology and improve soil and plant health. Carbon induction in the soil is maximised when healthy plants with efficient photosynthesis are coupled with soils that are fungal dominant.

Whilst in the United States the author visited Jonathon Keller of Penn Valley Farm, Lititz, Pennsylvania who produces 1500 tonnes per year of quality compost that is used in his organic corn, soy and wheat production and for sale to local farmers. He has been able to maintain SOM levels, decrease weed pressure and achieve yields similar to conventionally grown crops using a combination of compost applications, cover crops and careful crop rotations.

Jonathon also utilises a compost extract facility to produce “compost tea” that is applied as a foliar application. A three year trial using compost tea on neighbouring dairy pastures has resulted in a 10 tonne per hectare increase in silage yields. He believes that the increased pasture production is due to the microbial byproducts contained within the tea that feed and stimulates the existing soil microbes rather than the biology added from the compost (Jonathon Keller, Pers. Comm., 2014.). This trial supports the concept of carbon induction discussed previously, whereby the stimulation of soil biology results in improved soil and plant health.

2.4 Case Study – Pukeatua Peak Goat Dairy, New Zealand

Jeff and Fiona Graham operate Pukeatua Peak Goat Dairy near Te Awamutu in the North Island of New Zealand. The Graham’s 450 goats are housed year-round to aid in the control of internal parasites and pasture is “cut and carried” to them daily. Pastures consist of a 12 species herbal ley including lucerne, chicory, plantain, clovers, fescue and timothy. A 2100kg per hectare dry matter residual is maintained on pastures to optimise photosynthesis, with pasture harvested in a 30-day cycle (depending on growth).

The Grahams use a biological approach to soil and pasture management with the aim of increasing the depth of topsoil, maximising pasture quality and sequestering atmospheric carbon. Waste bedding from the goat shed is composted for farm use and commercial sale. 300 kilograms per hectare of compost is applied twice a year mixed with one tonne of lime, 250 kilograms of dolomite and trace elements to address soil mineral balance (based on Albrecht ratios). Molasses is added to provide a food source for soil biology. Jeff indicated that he is achieving a 40 to 50 percent increase in the effectiveness of the lime and dolomite applications with the addition of good quality compost.

Pasture production has increased from 14,000 kilograms of dry matter per hectare to 23,000 kilograms as soil mineral balance (68% calcium and 12% magnesium) has been achieved. Brix readings , a measure of dissolved solids in the plants sap and an indicator of nutrient density, of the pasture have improved from an average of seven or eight to 16 or 17 on sunny days. Total milk production has increased from 28,000 kilograms of milk solids in 2010 (from 600 goats) to 55,000 kilograms in 2014 from 450 goats (Jeff Graham, Pers. Comm., 2014).

Soil carbon sampling and measurement is being carried out on the farms pastures with the aim of eventually participating in the international soil carbon market.

Figure 3: Housed Saanen and Nubian dairy goats at Pukeatua Peak Goat Dairy

Source: P. Serle, 2014

Figure 4: “Cut and carry” of herbal ley using imported forage harvester.

Source: P. Serle, 2014

Chapter 3: Trophobiosis Theory

"*The relationship between plant and parasite is primarily nutritional*"

Trophobiosis theory, a thesis presented by Frances Chaboussou, an agronomist at the French National Institute of Agricultural Research, suggests that pesticide applications weaken plants, causing pest resurgence, which results in an increasing dependence on pesticide use. According to Chaboussou's theory, it is nutrient deficiencies and imbalances that lead to pest and disease outbreaks. Synthetic pesticides and fertilisers can also cause such imbalances and deficiencies (Chaboussou, 1985). The basis of this theory is the concept that the relationship between plants and parasites is primarily due to nutrition.

Chaboussou states that plants have two basic states – proteosynthesis and proteolysis. Proteosynthesis is the optimal state in which plants synthesise complete proteins and are immune to parasitic attack. Proteolysis is a state in which tissues degenerate causing simple sugars, nitrogen and free amino acids to accumulate in the sap. Most pest and disease organisms depend on the availability of free amino acids and simple sugars in plant sap as their food source and their increasing levels act as a signal for attack.

Chaboussou contends that the application of pesticides affects plant physiology, precipitating pest attack and disease susceptibility, leading to a further cycle of pesticide use. Further, applications of herbicides and synthetic fertilisers can lead to nutrient deficiencies in the treated plant. Any deficiency, especially in micronutrients, leads to an inhibition of protein synthesis and a corresponding rise in free amino acids.

Hence, plant pests and disease are the symptoms of an underlying protein synthesis problem and not the cause - pests starve on healthy plants. The author's travels and research has led him to believe that the in many cases pesticides are being applied to treat pest and disease outbreaks, without the underlying nutritional causes being addressed. A focus on plant nutrition that addresses mineral deficiencies would focus on treating the cause of pest and disease outbreaks and reduce farmer's reliance on pesticide (and herbicide) use.

Chapter 4: Latin American Study Tour

Part of this Nuffield study involved a tour to Latin America (Mexico, Costa Rica and Ecuador) led by Eugenio Gras, an international consultant and engineer and Kym Kruse an Australian regenerative agricultural educator. The tour focused on demonstrating simple, effective, low cost techniques to regenerate soils and reduce farmer's dependence on expensive synthetic fertiliser and chemical inputs.

Sixteen Australian farmers participated in the tour and visited farms producing avocado, citrus, banana, rice, vegetables, roses and livestock. Several of these farms were certified organic and supplied markets in the United States and Europe. The Latin American farmers visited highlighted the social and economic benefits they had gained from adopting biological practices. Reductions in input costs and an increase in margins were common. Social benefits were also noted, as labourers were keen to work on these farms without the danger of being exposed to dangerous herbicides and pesticides.

Fertility programs on these Latin American farms were based on the use of composts and bio-fertilisers. Several had managed to achieve a closed system in which all fertility requirements were sourced on-farm, producing significant input cost savings.

4.1 Bio-fertiliser Production

Bio-fertiliser production is the cornerstone of the fertility programs utilised by the Latin Americans. Production of bio-fertiliser involves the anaerobic fermentation of various biological bases (most commonly cow paunch or manure), enriched with milk, molasses, wood ash and rock dust with the addition of trace mineral sulphates and oxides as required. The fermented end product is a solution containing chelated minerals, hormones, biocatalysts and microbes utilised to regenerate and reactivate soil life and enhance plant nutrition and immune response to disease (Kruse, 2015).

Different biological bases are utilised, depending on availability, including bovine rumen contents and manure, grass and silage, decomposing organic matter (native microbes) and pumpkins. The end product varied depending on the length of time the contents were fermented. Typical products produced included a four-day "biol", utilised to reactivate soil microorganisms, a 30 day "bio-fert" utilised as a soil and plant fertiliser and a six to nine month "mother brew" which was used as the starter for new ferments.

Fermented grass/silage or decomposing forest material can be substituted for cow manure or rumen contents to utilise a different spectrum of microbes and add diversity to the ferments. Silage based ferments are utilised by the Latin Americans as livestock (and human) probiotics while aerobic biology collected from the forest can be reproduced anaerobically as many of these microbes are facultative anaerobes (organisms that are able to alter their metabolism to grow in either the presence or absence of oxygen).

Anaerobic soil conditions and anaerobic microorganisms are usually associated with poor health and pathogens, making many farmers question the role of fermentation in fertility programs. However, according to Gourlay (2014), anaerobic microbes play a major role in nutrient availability in the soil and facilitate carbon movement into the deeper soil clay layers. He advocates the process of "microbial balancing" to restore the integrity of the soil and plants, the key issue with this concept being the balance of beneficial microbes to pathogenic microbes.

Large quantities of bio-fertiliser can be produced with some very basic equipment. A range of "bio-factories" were observed from small scale fermentation facilities utilising 200 litre plastic drums and 1000 litre shuttles to large co-operatives using poly tanks for commercial bio-fert production. The ability to be airtight and the ease of installing an airlock to allow the escape of gas produced during fermentation, along with the ease of cleaning were the only limitations to the variety of vessels that could be utilised in bio-fertiliser production.

Figure 5: Bio-factory set-ups showing air lock for anaerobic fermentation

Source: P Serle, September 2013

Quality control testing is carried out on these ferments based on smell, colour and pH (desired between 3.5 and 4). A further qualitative test employed by the farmers involves mixing 25 millilitres of bio-fertiliser with 25 millilitres of 96 percent Ethyl alcohol in a cylinder, shaking and after 30 minutes assessing the amount of “jelly” rising to the top. This “jelly” indicates the level of microbial activity in the bio-fertiliser as the alcohol kills the microbes releasing their proteins, which form the “jelly”.

The Latin Americans also have access to a low cost (approximately $A40) laboratory DNA test allowing them to monitor bio-fertiliser quality and the diversity of microbes produced. These tests analyse the number of microbial families present and identify the presence of pathogens. DNA testing has demonstrated a dramatic increase in soil Channel Index (an index measuring diversity within an ecosystem) through the application of quality bio-fertiliser. The availability of this testing has enabled the farmers to confidently transition to biological and organic production systems utilising bio-fertilisers as their main fertility input.

Several other preparations useful for treatment of nutritional deficiencies and disease prevention are also utilised by the Latin American biological farmers. Lime sulphur is produced by stirring a mixture of lime and sulphur in boiling water and is used to control insects and fungal diseases. Extracts of various beneficial herbs and plants are prepared in either alcohol or boiling water and added to the bio-fertiliser or directly to the plant or soil.

Burning the bones of animals to release the phosphorus contained within them produces a powder containing approximately 42 percent soluble phosphorus. By adding potassium hydroxide during this process, soluble potassium is also made available and utilising rice husks during the heating process adds soluble silica. The powder is then added to the farmer's bio-ferts, eliminating the need to bring expensive synthetic fertilisers onto the farm.

4.2 Microbe Reproduction

Reproduction of commercially produced microbes is utilised by the Latin American farmers to increase soil microbiological diversity and suppress plant pests and diseases.

A commercially available culture of Bacillus subtilis is used as a soil and foliar spray to enhance the natural systemic resistance of plants. Bacillus subtilis acts as an antagonist and triggers an immune response in the plant, inducing long lasting protection against a broad spectrum of pathogenic microorganisms. Trichoderma, which has antifungal properties and aids in root protection, is used in potting substrates and as a seed treatment. The bio-fungus Metarhizium is used to control both insect and fungal attack of plant roots.

A specific group of naturally occurring, predominately anaerobic, beneficial microbes, commercially known as Effective Microbes (EM), were also utilised for disease suppression. Commercially available EM consists of five families of microbes:

1. Lactic acid bacteria (Lactobacillus caseii).
2. Yeasts.
3. Actinomycetes.
4. Photosynthetic (Phototrophic) bacteria.
5. Fungi.

Research indicates these microbes can suppress soil-borne pathogens, accelerate decomposition of organic wastes and increase the availability of mineral nutrients to plants. The activity of beneficial microorganisms like mycorrhizal fungi and nitrogen fixing bacteria is also enhanced. The organisms contained in the commercially available EM product were sourced from the surface of rice and the process can be easily replicated on-farm.

Lactobacillus inoculum recipe

Ingredients

- Cup of rice.
- 4 litre bucket with lid.
- 1 litre water.
- Fine mesh strainer.
- 10 litres milk.
- 20 litre bucket with lid.
- 4 teaspoons black-strap molasses.

Procedure

1. Place rice and water in four litre bucket. Stir vigorously until water is cloudy white. Strain and retain liquid.
2. Place lid on bucket (do not fully seal) and store in cool, dark place for 5-7 days.
3. Skim top layer off and strain the liquid (serum).
4. Add fermented serum to 10 litres of milk in the 20 litre bucket. Store in cool, dark place for another 5-7 days. Lid on (do not fully seal).
5. Skim curd layer from top and use as probiotic for livestock. Pale yellow serum remaining is unactivated inoculum.
6. Add 4 teaspoons blackstrap molasses as food for microbes and refrigerate for storage.
7. This inoculum can be used as a foliar or soil spray for disease control.
8. Further multiplication can be carried out by adding 5 litres of serum and 5 litres of molasses to a 200 litre drum of water. Stir and store for 5 days before use.
9. Dilute 1 litre serum in 20 litres of unchlorinated water for application to soil or leaf.

Source: Nutritech Solutions Sustainable Agriculture Course, September 2014

4.3 Chromatography

The Latin American biological farmers utilise chromatographic testing to assess the quality of soil, compost and bio-fertiliser samples. These simple, inexpensive “chromas” offer a qualitative assessment, providing an indication of the biological activity or interaction of minerals and organic matter within the substance sampled. An extract of the item to be tested is absorbed into a silver nitrate impregnated filter paper disk and the capillary properties of the filter paper separate the different substances contained in the sample. Pfieffer (1984) indicates that chromatography can be used to examine the complex interactions between organic matter, microbes and minerals that conventional laboratory tests do not accurately reflect.

Four zones of information are used to evaluate chromatography images. For soil and compost samples these zones relate to the following:

1. Central zone – organic matter and physical structure;
2. Inner mineral zone – fungal activity and mineral content;
3. Outer protein zone –bacterial activity, protein digestion and content and enzymatic activity, and;
4. Peripheral zone – nutrient potential and carbon sources.

Quality is determined by patterns (form) and colouration. Images collected over a period of time allow assessment of the effectiveness of the farmers fertility program in improving the mineral content, microbial activity and humus levels of their soil.

Figure 6: Examples of chromatographic images.

Source: P. Serle, 2015

4.4 Costa Rica Farmers Co-operative

Intensive organic vegetable growers in the Tapesco district near San Jose, Costa Rica, have established a co-operative that has 1,100 members and employs 70 people. Farmers in the region developed an aqueduct to provide irrigation water and as a result the area has become a hub of organic vegetable production. The co-op was formed to prevent government and corporate takeover of the farmers land in the 1980's.

The co-op provides marketing and packaging services for the grower's produce, finance and credit services and supplies the members with quality compost and seedlings. The compost and seedling production was established to reduce the grower's reliance on corporate agricultural companies and provide them with high quality inputs.

Two different quality composts are produced by the co-op. Both undergo a six-day period of compaction that promotes anaerobic fermentation before being either bagged and stored or spread out and turned daily for 28 days. The pre-fermentation of the raw materials has resulted in a 50 percent reduction in the amount of compost used by the growers to produce their crops.

4.5 Case Study – Rose Farm, Cayambe, Ecuador

At an elevation of 2900m, the rose growing operation of Falsto Falconi in Cayambe, Ecuador, had a number of competitive advantages. Situated close to the equator and at such altitude guaranteed strong sunlight to produce vibrant colours, good shelf life and an ample supply of good quality water (80-120ppm) from nearby perennial ice melts.

The business produces long stem roses, which are exported to 27 countries under organic certification. The stems are grown in hothouses, at a plant density of 85,000 per hectare, in what Falsto describes as a "super-intensive monoculture". A workforce of 150 people harvest approximately 30,000 stems each day from the 12-hectare operation.

In 2007, the business converted to organic production utilising a program of intense bio-fertiliser application and cover crops. The addition of biology, together with the action of the roots of the cover crops, alleviated the hard soil issues the farm had been experiencing. Falsto used a variety of vegetables as cover crops, which added diversity and organic matter to his soil and gave the added social benefit of providing fresh produce for his workers.

The adoption of organic practices resulted in major cost reductions, from $31,000 per hectare under conventional management to $4,400 per hectare under organic, underpinned by a 98 percentdrop in fertiliser use over seven years. A significant decrease in wastage was also noted, reducing from 15 to 3 percent with the change in production system. Water usage also reduced by 58 percent as the organic matter levels of the soil improved, with a commensurate increase in water holding capacity (Falsto Falconi, Pers. Comm., 2013).

Significant increases in productivity have also been achieved as the health of the farms soil has improved. Stems are sold by the centimetre with stem length ranging from 50 to 170 centimetres. Falsto has seen a 31 percent increase in stem length and a 51 percent increase in the number of stems produced per square metre since 2007 (Falsto Falconi, Pers. Comm., 2013).

Falsto has achieved some significant social and economic benefits by regenerating the health of his farms soil. He believes that farmers must learn to work with nature and create an environment where plants can express themselves (genetic potential). To this end he does not target supply for Valentines Day.

Chapter 5: Biodynamic Farming

Biodynamic farming is a comprehensive method of self-sufficient (closed system) agriculture that aims to create as much biodiversity as possible (Lovel, 2014). It has much in common with other regenerative farming practices, emphasising improving soil health through the use of compost and animal and green manures. The principles of biodynamic farming provide some extra methods that can be used in regenerative and organic systems to enhance biological activity increase flexibility and grow high quality products (Bacchus, 2013).

Biodynamic agriculture utilises specific fermented herbal preparations as compost additives and field sprays. The preparations each have a specific role in stimulating bacterial and fungal activity or making trace elements and minerals available to plants. Suggested modes of operation of these homeopathic strength preparations include nutrient addition (mainly micronutrient influence from foliar application), microbial inoculation, plant immune system stimulation and microbial signalling. Biodynamic practitioners also recognise that a relationship exists between plant growth and the rhythm of the moon and planets and time farming operations to coincide with astrological events.

Biodynamic management has been shown to benefit overall soil quality, increase available nitrogen and phosphorus in the soil and increase earthworm and microbial populations as compared to conventional agricultural management (Carpenter-Boggs et al. 2000). A review of studies that have compared biodynamic and conventional farming systems by Reganold (1995), shows that biodynamic systems generally have better soil quality, lower crop yields and equal or higher net returns per hectare than conventional systems.

New Zealand biodynamic consultant Glen Atkinson has developed a series of homeopathic preparations for use in horticulture and dairy. Research carried out by HortResearch NZ on his frost protection product in Gala apples showed reduced leaf burning and a 50 percent increase in flowering following a -2-degree frost. Anecdotal reports from dairy farmers indicated cows' preferentially grazed areas treated with homeopathic biodynamic preparations, with a corresponding increase in milk production.

The commercial production of the herbal preparations by organisations such as Biodynamic Agriculture Australia Ltd has enabled much easier integration of the biodynamic preparations into regenerative agricultural practices. For example, the preparation referred to as soil activator contains small amounts of all the biodynamic preparations and is applied to activate the soil when first beginning with biodynamic practices.

Chapter 6: Grazing Management

Rotational grazing management is an integral part of regenerative farming practices. Plants and animals have co-evolved over millions of years, resulting in complex inter-relationships. Grasses, in particular, have evolved in association with herbivores and have adapted to periodic defoliation (grazing), followed by a period of rest. Many grasses need to be grazed in order to be more productive. High density, short duration grazing which mimics the herding and grazing patterns of wild ruminants promotes carbon capture in the soil and increases biomass production.

The basic principal that underlies the high density, short duration grazing advocated by regenerative farmers is that overgrazing is a function of how long a plant is exposed to grazing and how long before it is re-grazed (Murphy, 1998). The length of time plants are rested is dependent on the growth rate of the plant. Plants that are given sufficient recovery time after being grazed can rebuild energy reserves and root systems, allowing photosynthesis and biomass production to be maximised.

Mob grazing, Management Intensive grazing, Cell grazing and Holistic Planned grazing involve multiple paddocks, high animal densities, very short grazing periods, long recovery periods and higher stocking rates. Animals are run in large mobs, consuming approximately 40 percent of the available biomass and trampling the balance to feed soil microbes. Overgrazing is avoided and plants are allowed to fully recover from grazing before animals return.

Farm based research comparing multi paddock grazing at high stocking rates with both light and heavy continuous grazing resulted in increased soil organic matter and cation exchange capacity under rotational grazing. The ratio of fungi to bacteria was also higher indicating improved water holding capacity and nutrient retention and availability. Best practice multi paddock grazing sequestered 11 tonnes of carbon dioxide equivalent per hectare per year more than heavily stocked continuously grazed prairie (Teague, 2011). These results support the anecdotal evidence from farmers suggesting that appropriately managed rotational grazing systems improve forage and livestock production and have positive effects on soil health.

Missouri grazier Greg Judy has been utilising Holistic High Density Planned Grazing for around a decade, running 250 South Poll cows and some sheep on 1200 acres. He has been able to significantly reduce his cost of production, with the only farm input being free choice minerals. Holistic Planned Grazing has enabled Judy to lower his cost of production per cow per annum to 10 percent of the standard industry benchmark whilst achieving significant production increases along with improved soil health (Greg Judy, Pers. Comm., 2014).

On the Judy farm, animals are given ad lib access to a range of trace elements and salt licks to address any dietary deficiencies. It is estimated that stock utilise about 25 percent of the licks they consume with the remaining being returned to the soil in their manure, helping to achieve soil mineral balance over time.

Trials to assess the application of compost tea as a biological inoculant are being established on the property. Monitoring of soil mineral availability, dry matter production and soil biology will be carried out with the aim of doubling production with the increased biological diversity in the soil.

Joel Salatin of Polyface Farm, Virginia has achieved similar production and soil benefits by utilising mob grazing. Salatin has been able to lift his stocking rate to 400 cow days per acre (approximately one cow per acre) in contrast to the county average of 80 cow days per acre (four acres per cow) (Joel Salatin, Pers. Comm., 2015). Pasture production has doubled after moving from a two-day grazing period to daily cattle moves.

The author noted during his travels that many of the “grass” farmers visited had added an extra layer of diversity to their operations by including a pasture based poultry enterprise. Some of the benefits of this diversification included extra income, insect and weed control and an added fertility source. As an example, Roman Stolzfoos of Springwood Organic Farm, Kinzers, Pennysylvania runs 2800 pastured laying hens behind his rotationally grazed dairy cattle. The hens aid in fly control for the cattle and eggs are mostly sold wholesale.

Conclusion

A fundamental change in agricultural practices is required to improve soil carbon levels and soil health. Soil biology needs to be actively managed to optimise the biological pathways that directly contribute to plant productivity and carbon and nutrient cycling within the soil. Management practices require a focus on optimising photosynthesis to provide the soluble carbon that soil microbes depend on as a food source.

Innovative farmers are using simple, cost effective methods to increase microbial populations and diversity and address mineral deficiencies in their soils. Improvements in soil organic matter levels and farm productivity are being demonstrated as soil biology is regenerated and plant nutrition is optimised.

Recommendations

Improving soil health by utilising regenerative farming principles requires:

- an understanding of soil mineral and microbial balance, with a focus on plant nutrition to address mineral deficiencies and reduce disease incidence.
- maximising soil cover and maintaining actively growing roots to support soil microbes.
- optimisation of photosynthesis and the "harvesting " of sunlight to stimulate and feed the soil microbial population.
- increased biological diversity – plants, animals and microbes.
- a focus on increasing soil carbon content through management practices which stimulate soil microbiology.

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Plain English Compendium Summary

Project Title:	Regenerative Agriculture: A soil health focus
Nuffield Australia Project No.: Scholar: Organisation:	 **Paul Serle** **Nuffield Australia**
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Objectives	To gain an understanding of soil health parameters with regard to improving agricultural production and increasing soil carbon content. Investigate simple, on-farm methods of achieving soil mineral and microbial balance.
Background	Agricultural soils have lost 30% to 75% of their original soil organic carbon content. Conventional, high-input farming practices are oxidising carbon from the soil. A fundamental change in agricultural practices is required to improve soil health and fertility.
Research	Regenerative, organic, biological and biodynamic farmers, agronomists and consultants were visited in New Zealand, United States, Canada, United Kingdom and Latin America.
Outcomes	Regenerative farming practices involve the management of farm soils to improve their capacity to sequester and store carbon, resulting in improved soil fertility, water holding capacity and agricultural production.
Implications	A focus on soil health and increasing soil carbon content can result in improved farm productivity.
Publications	