Biological Farming:
A Practical Guide

A report for

NUFFIELD AUSTRALIA FARMING SCHOLARS

2007 SCHOLARSHIP REPORT BY

Dr. Catherine J Harvey

Completed November 2007

Sponsored By:

Sidney Myer

SIDNEY MYER FUND

Scholar Contact Details

Dr. Catherine J Harvey

"Tauwitchere" Narrung SA 5259
Phone: 08 85754255
Fax: 08 85754255
Email: tauwitch@lm.net.au

Nuffield Australia Contact Details

Nuffield Australia

Telephone: (02) 6964 6600
Facsimile: (02) 6964 1605
Email: enquiries@nuffield.com.au
PO Box 1385, Griffith NSW 2680

Table of Contents

Contents

Executive Summary

Biological Farming – starting from the ground up.

Conventional modern farming systems teach us to be reactive to symptoms, rather than to causes. Consequently, we rely on ever increasing rates of herbicides to kill weeds, fungicides to control diseases, insecticides to eradicate crop pests and animal parasites and inorganic fertiliser to feed our plants – no wonder they call it 'more-on' farming.

Biological farming works on the principle of balancing all soil parameters with the aim of developing a self -regulating system. The soil is at the heart of biological farming and when the soil's chemical, physical and microbiological properties are in balance a productive system can be achieved. Many problems disappear as they are caused by imbalanced nutrients, loss of competing soil biology and undesirable soil structure.

I am convinced that improving soil conditions to enable soil biology to perform at optimum levels can reduce our dependence on the myriad of chemical inputs and improve the nutritional value of the food we produce. But, how can biological farming practices be applied on large scale Australian farms and how can the progress and results of their application be measured? These two questions were at the heart of my Nuffield Farming Scholarship.

The more I discussed biological farming with people in the UK, Canada, the USA, India and here in Australia, the more convinced I became of the importance for farmers to understand the physical, chemical and biological properties of their soils. These three factors are intertwined; change one property and changes for better or worse will occur in the other two. For example, boosting the carbon supply to soil organisms by using pasture, a green manure crop or compost has been shown to not only increase the biological population but also to increase soils moisture retention; improve the cation exchange capacity (CEC), nutrient retention and availability; and improve soil structure. Another important factor now being considered is the type of

carbon in the soil based on its stability. This is paramount to the long term improvement of soil carbon content. We now need to focus on the intermediate and stable carbon which persists in the soil for a few years to hundreds of years eg: glomalin produced by mycorrhiza and stable carbon in the form of charcoal.

There are many simple soil tests that can be done on farm to establish the physical, chemical and biological health of the soil, many of which are discussed in this report. However, measurement of microbiological soil properties remains an area of contention.

I found minimal independent peer reviewed research in this area, especially in relation to the provision of practical tests to measure the microbiological food web in a soil, compost or compost tea. In the field direct microscopy was the favoured method but this is not supported by academics, despite farmers seemingly achieving useful results.

How much biology is required? What combinations of soil organisms? These are much debated questions. I visited farmers who were able to correlate in paddock production differences with ratios of bacteria to fungi based on 'Soil Food Web' tests. However, I conclude that if we can increase balance the soils CEC and increase carbon food sources in the soil the biology will return and be able to look after itself. Except in the case of mycorrhiza, where reintroduction is may be necessary.

Compost either as a solid or liquid compost tea, is held-up as a key input for successful biological farming. It is a rich source of carbon/carbohydrate for soil organisms and soil micro organisms, but is it feasible to produce sufficient compost for large scale farms, with low carbon soils? Having visited small farms, applying biological principles, that are struggling to produce and apply sufficient compost or compost tea, I conclude that these preparations are impractical in most situations as the major source of carbon for large scale operations. As all plants secrete sugars (carbon), from their roots, we need to focus on building soil carbon from this source.

Therefore, I explored this and other methods to introduce large quantities of carbon to our soils.

One of the most exciting products I discovered was Bio-char/charcoal. Bio-char is a stable carbon source produced when organic material is burnt in minimal oxygen (pyrolysis) concentrations. In trials where Bio-char has been added to the soil crop yields have increased by between 10 and 300%.

An innovative Canadian farmer showed me a system he had developed to inject diesel exhaust fumes back into his soil. Initial results showed increased growth of beneficial soil microbes.

I believe a combination of techniques such as seed dressings of mycorrhiza, green manure and stubble digestion, will help large scale farms increase soil carbon insitu. In the future I think bio-char and diesel fumes injection will also be techniques applied in Australian biological farms.

I have looked closely at common biological fertilizers/foods used in BF to increase soil microbial populations. These foods increase different microorganism populations and are rate dependant. I have included practical information on compost tea brewing and spraying for larger scale applications that would have been useful when I began using this process.

Having completed my study I feel I still have more questions than answers but that I am much clearer about what is achievable and the practicalities of applying biological farming practices on large scale farming operations.

I hope my report provides a useful document for others wanting to use and quantify biological farming practices.

Acknowledgements

I would like to thank:

Firstly my husband David who gave me total support in applying for and completing my scholarship. He shouldered all the worries and responsibilities of the farm and family during the 2006/7 drought.

The Australian Nuffield Australian Association for promoting and organising these wonderful learning experiences.

The Sidney Myer Foundation for providing me with the opportunity to carry out my study.

Our staff who helped Dave keep the farm working.

The Nuffield’s who provided hospitality and friendship, especially Jo Scammel.

The many people whom I visited and who freely shared their time and knowledge, especially Gerald and Verna Wiebe for showing me that the biological farming principles do work!.

Lastly I would like to acknowledge my daughters Veiss, Alex and Josie who kept me in touch with their lives while away.

Aims

My aims in this study were to gain a thorough understanding in the different theories, applications and methodologies in biological farming. Initially my focus was on soil micro organisms and their measurement. I soon realised that all parameters of the soil needed to be monitored. Many speakers have come to Australia advocating theories and methods for this type of farming. I wanted to investigate farms employing their theories and methods and see how they monitored their farming, the practicality of BF applications and the success they had using different approaches. I also realised to compare different approaches and their success you needed to be able to measure parameters. Hence I needed to understand the different tests and the relevance of their measurements.

I realised as the study progressed that the tests are only guides. There is no single all encompassing test, as with any diagnosis you must have subjective observations and objective measurements. These must then be processed and interpreted and individual results weighted based on all the findings. After arriving at a diagnosis a plan of treatment can be implemented. The soil that you are measuring is a living entity and you have but a snapshot of the soils parameters in time and these change according to different conditions and treatments. Therefore monitoring is an ongoing process and the treatment plan will change according to the soils progress.

So not only did I look into different scientific methods to analyse and monitor BF, I also visited farms using the principles from the three different international speakers whom I had heard speak. I wanted to see the results these farms were achieving and how they practically implemented the principles advocated by the speakers.

The final objective was to provide practical data for people who have decided to practise biological farming methods. As I mentioned there are many pitfalls and snake charmer salesmen trying to profit from selling farmers products that may be ineffective, unnecessary or have cheaper alternatives. As I went along I came to realise that an integral component of biological farming is about balancing the cation exchange capacity and increasing soil carbon content. I began examining different routes to this goal. Then I discovered even this was complex as there are different types of carbon and this affects their longevity in the soil and how they affect the soils micro organisms. Topics I had no idea existed. So for every door I went through I would find even more doors to enter to pursue knowledge in BF. It has been and continues an exciting journey in understanding what lies within our soils and how we may improve soil health and in turn produce superior nutrient crops, pastures and foods.

Background

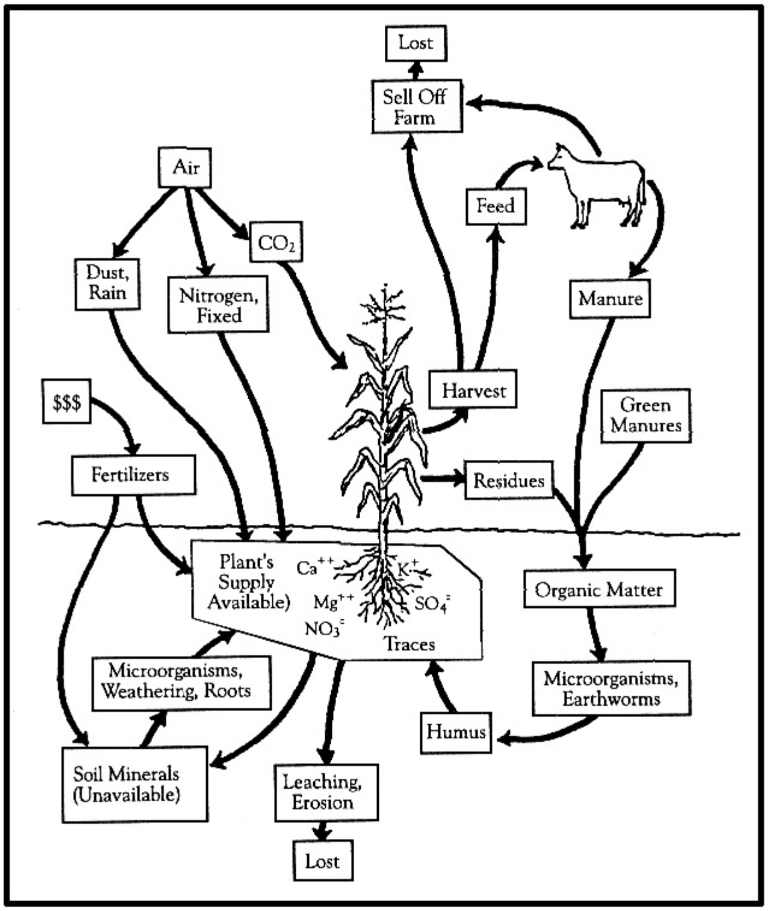
I grew up in Adelaide but always have had a love for the land and animals. After completing my veterinary degree I went to work with small animals. Within two years I met and married David Harvey, a dairy farmer. I have since worked as a veterinarian and farmer. My husband and I have been farming for 22 years on 2300ha of land situated between Lake Alexandrina and the Coorong. We hands on manage a: 400 cow dairy, 350 cow beef herd and crop 800 ha. We noticed that despite following what was considered best practice that: our pastures were not long lived, our dairy cows produced less and their fertility was declining, our crops required more and more herbicides, pesticides and fungicides. Our soaring input costs were largely due to the chemicals and fertilizers. We had no better pastures or crops, in fact as time went on the soil was becoming more weed infested and pests numbers were increasing. I was frustrated that the cows were not producing the amount of milk that was predicted using a convention nutritional computer program based on our feed test analysis. It seemed that the fodder we were growing was lacking something that was not being measured. We then began learning about biological farming. We learnt that the nutrient density of modern fertilizer force fed crops/fodder was much lower than crops/fodder grown previous to the green revolution.

Biological Faming is about improving and balancing the three components of soil: physical, chemical and microbiological. The farmer works with nature, not against it. BF is about maximising the nutrient flow cycle, **our soils have potential to convert nutrients from the air and within to bio-available minerals and foods**. The more efficiently your soil works the less need for artificial fertilizers. BF looks at the cause of the problems not simply treating the symptoms with chemicals. The improved soil results in: increased soil micro-organisms which increased nutrient availability to plants, increased soil carbon, improved soil water holding capacity, reduced erosion, reduced pest, weeds and diseases. Increasing soil organic carbon by 1% increases the water holding capacity of soil twofold[1]. It is important to emphasise that micro-organisms in the soil are essential for providing and facilitating plant nutrient uptake. Herbicides, fungicides, pesticides and tillage all have a negative effect on the soil population's balance. Soil microbes are necessary to fix carbon into the soil rather

[1] Christine Jones

than allow oxidation losses into the atmosphere as would happen in most no till stubble retention situations.

Figure 1: Nutrient Flow diagram



Nutrient Flow diagram
This shows simplified flow of nutrients in a farming situation. Note mycorrhiza would be between roots and ions. Also sugars are being pushed out from plant roots.

Source: *Biological Farmer.* Gary Zimmer, p 83

We have listened to international speakers who propounded different paths to achieving success. BF can be achieved in different ways but which way would suit us best? We found that we had wasted money on inappropriate equipment and products. We found a big gap between the theory and the practical applications. I felt strongly motivated to find ways we could scientifically analyse what we were doing to gauge the efficacy of methods we were adopting. I bought a microscope and oxygen meter and began to analyse compost tea brews. This enables me to control and understand what I was applying to the soil. It also enabled us to monitor the products we were purchasing. We found these were not giving the results that were promised.

This then led to my desire to find out how to monitor biological farming and find practical applications for Australian agriculture.

Introduction

Although crop yields have increased since the introduction of inorganic salt fertilizers, herbicides and pesticides there has been a concomitant decrease in nutritional integrity of crops. Research shows that the mineral content of food has decreased by an average of 40% compared with levels fifty years ago.

Figure 2: Changes in Food Mineral Composition from 1940 to 1991

Element	% Change in Vegetables	%Change in Fruit
Copper	-76	-19
Sodium	-49	-29
Calcium	-46	-16
Iron	-27	-24
Magnesium	-24	-15
Potassium	-16	-22

Source: *The Composition of Food*. The Ministry of Agriculture, Fisheries and Foods and the Royal Society of Chemistry, UK

This decrease in mineral content of food is incredibly important for all creatures consuming the food! Enzymes catalyse every chemical reaction in our bodies. Every enzyme needs a mineral/s to act as the catalyst. Enzymes are part of all body systems which include your immune, hormones, nerves, muscles, digestion, reproductive and homeostatic systems. Traditional diets consisted of food that was not processed, not denatured, and consisted of active enzymes. Our modern diet now consists of less minerals and enzymes than fifty years ago. Many health problems can be prevented by correct nutrition.

I realised that even before you 'measure so you can manage' the soil, you must truly understand what you are testing and the science behind the processes in the soil.

Having a sound knowledge of soil biology and chemistry means that you can be confident that recommendations are not based on what advisors want to sell but what your soil requires.

Most of the advisors I visited having successful results with their clients farms were people with comprehensive backgrounds in science. They understood at a tertiary level one or more of the fundamentals in chemistry, physics or biology. They could then work from first principals in analysing an individual's farm and make recommendations based on this thorough overall understanding.

Agriculture is a combination of chemistry, physics and biology. Having a good understanding of these principles allows them to understand the cause and effects of what is happening in the soil and growing plants. Much of the research has been done on these parameters many years ago. Over the past 150 years there has been excellent research on the basic principles of soil biology. One of the most informative publications available on agricultural microbiology is "Soil Micro-organisms and Higher Plants" by N.A. Krasil'nikov USSR and is available to download from the web. (Approx 400 pages). This contains information on more than 400 case studies.

This research is now totally ignored by many modern agricultural scientists. Many scientists now only look at a small part of the soil picture rather than having a holistic view. Funding sources drive agricultural scientists' research focus. A large proportion of universities funding comes from outside companies looking for a product that can be commercialised. One researcher I spoke to said this is an important reason why little research had been done on BF.

I will describe tests that can be done on and off farms. Philip Callahan Ph is a scientist whose lifelong quest has been to understand and explain physiology in nature. His specialty was communication between and within cells and between organisms. He told his students to 'see what you look at'. On farm monitoring is as important as off farm laboratory tests.

Biological farming is not just one method; there are a number of methods to achieve the same goal. I was fortunate enough to visit some innovative farmers and researchers who used basic principles to improve their farm outcomes.

I will then describe some old and new methods being used on farms. I will highlight some important areas to consider in these methods.

In the references I have listed further reading and web sites.

Understanding Soil Basics

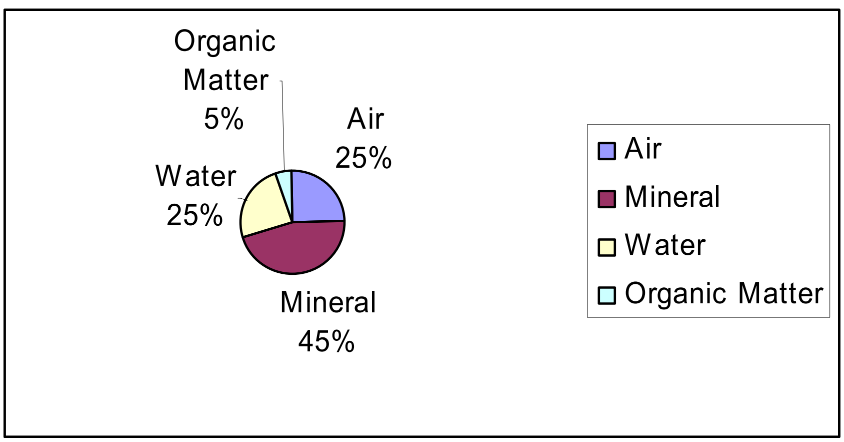
Physical soil structure

The soils texture and structure relates to aeration and drainage. This is influenced by the soil microbiology, soil chemistry and physical soil disturbances, eg ploughing and animal traffic when wet.

Soil microbiology is important in the formation of micro-aggregate and macro-aggregate structures. These aggregates hold the soil together and provide structure for air spaces. Micro-aggregates are clumps of bacteria, fungi and plant material glued together by substances produced by soil bacteria and fungi. Research shows that glomalin produced by mycorrhiza may be one of the most important substances in promoting and stabilizing soil aggregates. The micro-aggregates are then held in position by fungal hyphae. These structures provide spaces in the soil for air, water and micro-organisms.

Ideal soil structure comprises of 45% minerals, 25%water, 25%air and 5% organic matter.

Figure 3: Soil Composition.



Source: *The Biological Farmer*. Gary F Zimmer. p 40

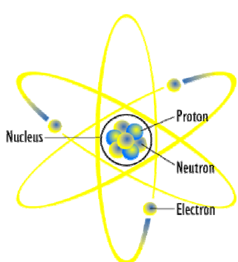
The effect on the physical structure by chemical and microbiological matter will be discussed in subsequent areas.

Soil Chemistry

Chemical elements have characteristics that dictate how they behave in the soil and therefore affect soil structure and mineral availability….PHYSICAL AND CHEMICAL properties of Soil. The following is some chemistry background to help you understand soil chemistry.

Elements are pure substances that cannot be decomposed by a chemical reaction. There are 109 elements on earth listed on the periodic table. Eleven elements make up 99% of the earths crust and the atmosphere. Oxygen makes up approximately 50%, silicon is 25% and only 25% of elements occur in a free state. The rest are combined with the same or other elements because of their atomic properties.

Figure 4: A simplistic diagram of an atom



An element consists of an atom, which is made up of a central nucleus. The nucleus contains neutrons (neutral charge) and protons (positive charge). Whizzing around the nucleus in orbits are electrons (small sub atomic particles with a negative charge). Electrons are the main base of energy exchange in biological systems. If the atom does not have the same number of electrons and protons it will have a charge, it is then called an ion. An ion with a positive charge is a **cation** and an ion with a negative charge is an **anion**. Eg hydrogen has 1 proton and no electrons, so it has an overall +1 charge, making it a cation.

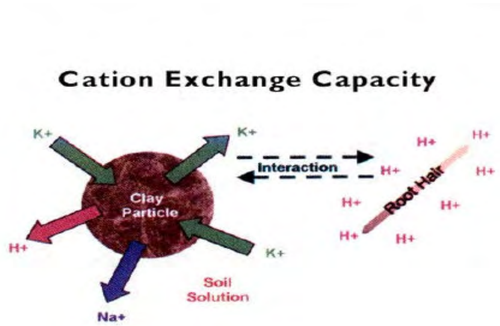
Atoms will form bonds depending on their charge. Oppositely charged ions attract each other and form ionic bonds in ionic lattices. Because of their charge the ionic lattices will conduct electricity and dissociate when added to water. (Salts disassociate in water to form ions). Understanding these principles is important to understanding what happens to fertilizer when added to soil and interpreting soil test results. Soil is made up of ions that interact with each other. The cationic exchange capacity (CEC) depends very much on the soil element composition, which in turn is dependant on the parent rock and the level of weathering that has occurred. Particle size can vary from gravel to coarse –sand through to fine silt and clay. Clay is the soil term that describes all particles less than .002 mm. Clays are anionic particles and therefore repel each other, which is why in water they are held in suspension for many hours and so are termed “colloids”. Each of these particles can attract and hold a number of cations, the most important cations being calcium, magnesium, sodium, potassium and hydrogen. Organic matter is also anionic. Organic matter has more negative sites around it than clay and hence can hold more cations. The more colloids (anionic particles) in the soil, the greater the soil’s capacity to hold cations. Hence clay soil has a greater CEC than sandy soils. To **maintain equilibrium anionic sites must always be filled**, so if **you remove a cation from an anionic site it must be replaced with another cation**!

The CEC mechanism is one of the most important ways that plants obtain nutrients and it therefore has a strong influence over soil structure and agricultural productivity.

Sandy soil has a low CEC because it has low clay and organic content**. By increasing the amounts of colloidal clay and organic matter (carbon) in the soil we will INCREASE the CEC capacity (electrical charge), which increases the availability and reserves of nutrients to the plants.** This is measured in milliequivalents (Meq).

The CEC is the hub of a dynamic system. It has interrelationships with plant roots (via other soil micro-organisms), the soil solution and the elements that are being weathered to form new soil. The cations in the soil come from salts dissolved in soil solution and minerals in the soil. Hydrogen is a by-product of organic processes such as exudates and decomposition. Hydrogen is the main currency, as plants exchange the hydrogen cation for other desired cations such as calcium.

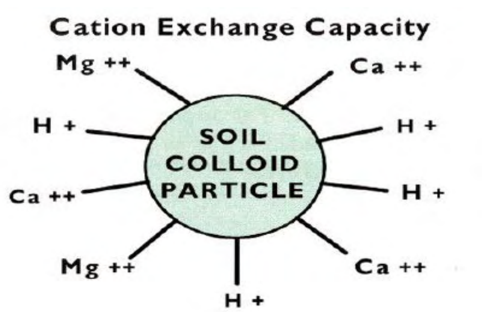
Figure 4: Cation exchange



Source: Nuffield Report; A Practical investigation into vitamin and mineral nutrition of high yielding dairy cows. Josephine Scamell. page 19

Soil pH is a logarithmic measurement of H+ ions in the soil. High or low Ph's interfere with nutrient availability because of the ionic interactions. All the electrical energy of the colloid portion of the soil tells us how much potential there is in the soil to react with other nutrients.

Figure 5: Diagram to Illustrate Cation Attraction to Negatively Charged Soil Particle



Source: *Nuffield Report 2000,* Josephine Scammell

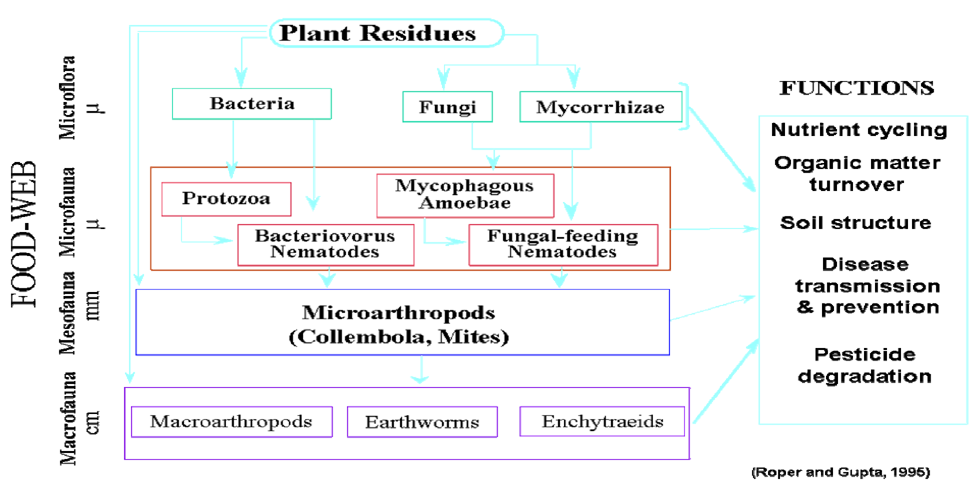
Soil Biology

Soil microbiology is a complex ecosystem. Soil micro-organisms can be broadly grouped into:

- Bacteria, aerobic species are beneficial, anaerobic species can be beneficial or pathogenic
- Saprophytic fungi
- Mycorrhiza fungi which can be further divided into vesicular arbuscular endomycorrhiza (hyphae penetrate root cell and exchanges nutrients, can increase roots absorptive area by 100 times), ectomycorrhiza and ectendomycorrhiza both colonize tree root tips
- Nematodes which can be fungal, bacterial and predatory feeders(Sandy soils have few or no earthworms)
- Protozoa are divided into flagellates, amebae and ciliates. They feed on bacteria and release nitrogen into the soil. Ciliates flourish in anaerobic conditions
- micro arthropods eg soil mites

CSIRO scientist Gupta VVSR has drawn up these conceptual diagrams explaining the interrelationship of the different groups and their functions.

Figure 6: The Soil Food Web



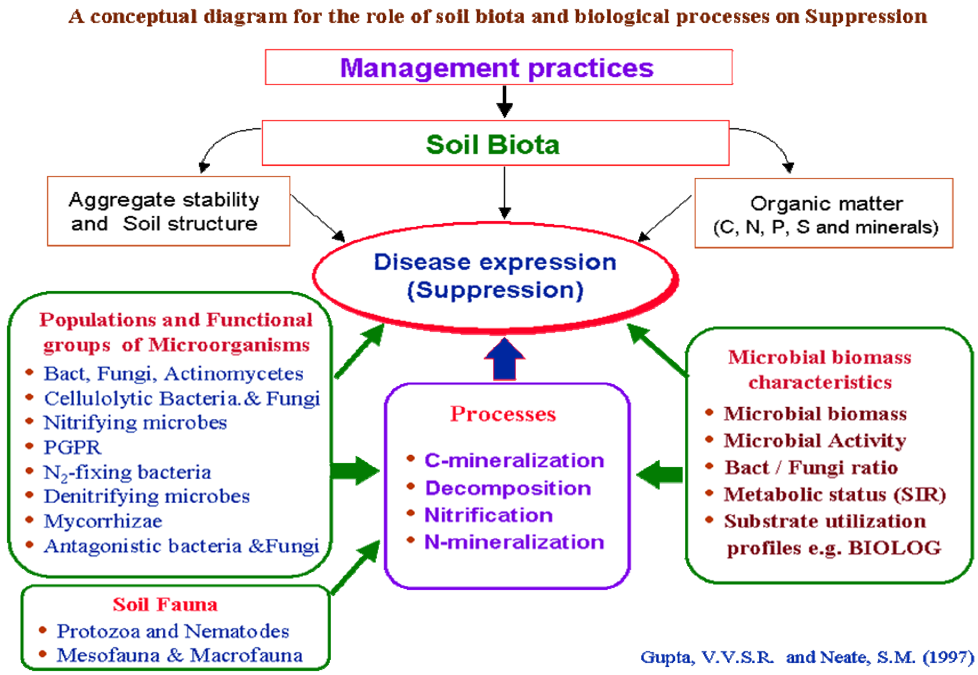
Source: Roper & Gupta

Beneficial functions the soil food web performs include:

- decomposing raw organic matter to release nutrients
- producing biologically active carbon including humus. *'Stable or inactive humus is generally not a factor in the biosystem and can sometimes be a liability because of its hydrophobic properties, its possible content of toxic residues ,and its required energy of activation. Humus becomes inactive upon repeated sterilization by toxic materials and from continuous dehydration by mineral salts.*[2]. Arden Andersen
- mycorrhiza exchange nutrients with plant roots using their extensive mycelia to access food and water from areas away from the roots
- act as supply of non leachable nutrients
- produce plant growth stimulants such as enzymes, vitamins and hormones
- protect roots from invading disease bacteria, fungi, nematodes and some insects
- Improve soil structure, by formations of bacterial microaggregates and fungal forming macroaggregate. This reduces erosion, holds water and nutrients and increases soil aeration
- Glomalin is a recently discovered powerful glue substance secreted by hyphae of fungus called Glomulus (mycorrhiza VAM). It holds soil particles together as aggregates and helps give soil structure. Research shows mycorrhiza and therefore glomalin content is markedly reduced in tilled soils
- Detoxifies soil by breaking down toxic chemicals
- Rhizosphere microbes release chelating agents which increase the availability of many soil nutrients, release growth promotants. Also release antibiotics to protect root surface from pathogenic microbes
- Some fungi can control nematodes by forming a "noose" and snaring them

[2] AA Science in Agriculture

Figure 7: Functions performed by soil food web.



Source: Gupta V.V.S.R.   CSIRO

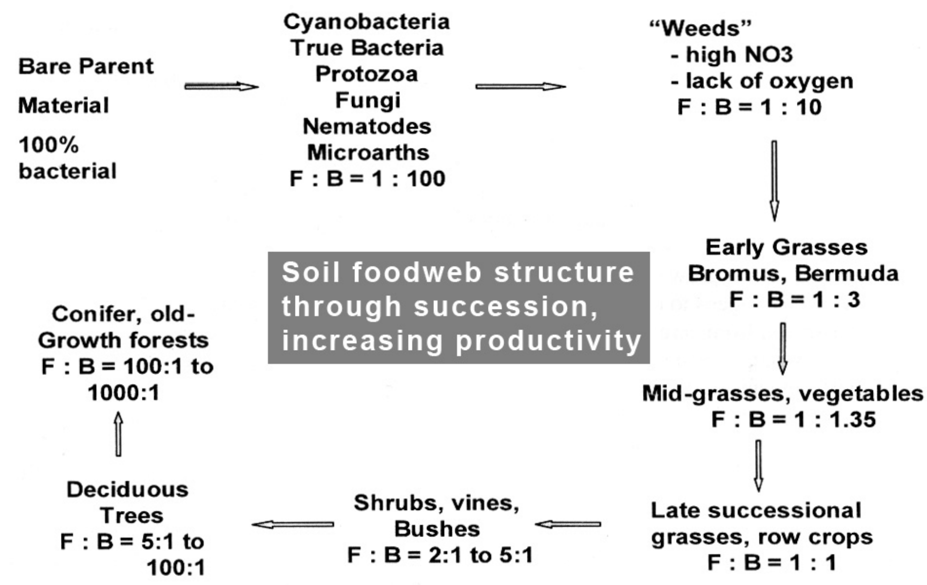
Soil micro-organisms requirements for survival are the same as all living creatures: a comfortable home, food, water and oxygen. Disturbances, which interfere and upset these requirements, are: tillage, compaction, salt type and anhydrous fertilizers, herbicides, fungicides, pesticides, drought, flood and monocultures.

All organisms are made of cells. Understanding cell wall structures helps one understand how fertilizers, herbicides and pesticides affect and harm these structures. Most fertilizers are salts and cause dehydration of cells causing cell death or inhibiting microbial growth.

Elaine Ingham (EI) is a US soil scientist who has formed her own company called Soil Food Web (SFW). This company has laboratories around the world that analyse soil, compost and compost teas based on her own tests. EI did thousands of soil tests and correlated findings into tables based on plant species growing there. Unfortunately this work has not been published or peer reviewed. Biological consultants that I met with all agreed with her basic theories and found her SFW tests useful when analysing compost teas and soils. Gerard Wiebe (GW) used the Reams tests to improve his soil. After a number of years he had balanced his soil to ideal parameters and should have been growing fantastic crops. But this was not the case. He found that the difference between paddock crop yields was not explained by the chemical Reams test.

When he heard EI speak he realised that the soil food web could be responsible for the differences in paddocks' performances. When he tested the soil with the SFW he found his best soil had a bacterial to fungal ratio of 1:1. The average performing soil was 1:0.5 and the poorest soil was 1:0. EI proposes that cereals do best in soils with a 1:1 ratio.

Figure 8: EI proposed soil bacteria:fungal ratios for different plants



Source: Dr Elaine Ingham. *"True Fertility Workshop."* 27th February 2006

There is also controversy surrounding the theory that by providing the foods and right conditions for soil microbes that they will flourish and return. Lyn Carpenter-Bloggs said a common saying amongst soil scientists is ''everything is everywhere, the environment selects '.i.e. the micro-organisms do not have to be reintroduced to the soil. If cover cropping (food) and balancing minerals were enough to bring the soil food web back into balance then why did this not happen on GW farm?

Soil Tests

The following are the tests commonly used to quantify and qualify soil parameters to monitor biological farming. I have divided them into the three categories of soil I have previously discussed: physical, chemical and biological.

Jo Scammel, a Nuffield Dairy nutritionist, teaches her farmers to look at the soil. She takes them out to their pastures with a shovel and digs up a square of soil. From this you can assess soil structure and soil biology. “See what you are looking at”

The following are tests to help monitor the soil.

Physical Soil Tests

1. Penetrometer Test: a penetrometer is a metal rod with an attached pressure gauge. The rod is pushed into the soil and pressure readings taken as the probe progresses downwards. It measures soil density. The readings vary as you go deeper and in most agricultural soils you will reach a hardpan which affects water and root penetration. Gerhard Wiebe told me he has rid his hard pan since biologically farming. A shovel can produce a similar but rough guide.

2. Digging allows you to examine the soils:

- crumb structure
- Root :depth, volume, colour and elasticity
- Earthworms morphology and numbers are good indicators of soil health in high moisture soils. They proliferate in soil that is high in calcium and has good structure i.e. air and plenty of food. Worms can be objectively assessed for numbers (it desirable to have 25worms/square foot this means excellent health, while below 5 is poor) and different sizes. Subjectively they can be graded on: colour (dark colour indicates plenty of bacteria present in soil have been consumed), activity of worm on hand, (should become more active as they heat up) and finally evidence of reproduction. Not all soils have worms but can still be healthy eg sandy soils rarely have worms
- Soil Smell: rancid /sour smell would indicate anaerobic conditions. Could be due to being waterlogged or compacted. Soil should smell earthy
- Ants in dry soils perform similar function to worms in the soil

Ideal soil has a loose crumbly texture. When moist it can be squeezed together and will not fall apart. As stated before bacterial microaggregates and fungal content (glomulin) hold minerals, air and water in a house like structure. Electron microscope pictures show a tremendous difference in soil that has been conventionally farmed cf to biologically farmed. The conventionally farmed soil has the appearance of a solid lunar landscape while biologically active soil has a sponge like structure with much texture.

Chemical Soil Tests

Most farmers have done chemical soil tests. These are a good starting point in monitoring BF practices and giving basis to a plan.

Conventional soil analysis reports on nitrogen N, phosphorus P, potassium or potash K, magnesium Mg and pH evaluation. This report was first advocated in France "Academie d"Agriculture" where in 1897, Gabriel Bertrand succeeded in showing that a "dust" of the soil (that is to say a mineral in trace element form), was essential to the functioning of living cells. Justin von Liebig developed the theory called Leibigs' Law of Minimum. This states that growth is not controlled by the total of resources available, but by the scarcest resource. He put forward N, P and K as the major minerals to supply. He later realised that this was not correct but his correction was ignored. Many elements at this period in time had yet to be discovered. Initially concentrating on these elements work well in good soils. After time, many of the nutrients in the soil can become "locked up" and unavailable to plants or leached out. The results of heavy fertilizer use, herbicides and pesticides have resulted in soils becoming compacted and sterile. The fungi die off and leave behind bacterially dominant soils. Bacterially dominant soils favour weed and Brassica species growth. More fertilizer, herbicides and pesticides are required to be applied to maintain production i.e. "more-on" farming. It then becomes a large scale example of hydroponic farming with large amounts of fertilizer being leached through the soil as the soils become less able to 'hold the nutrients' or deliver the nutrients via micro-biology.

Biological farmers usually use soil tests based on the Albrecht, Reams or Mikhail methods.

Albrecht Method

William Albrecht is considered by many as the pre-eminent soil scientist of the 20th century. His published scientific papers spanned over 56 years beginning in 1918. Albrecht used lab tests that measured nitrogen, sulphates, phosphates, calcium, magnesium, potassium, sodium, cobalt, boron, iron, manganese, copper, zinc and molybdenum as well as total exchange capacity, pH and humus content. He spent much of his research defining the optimum levels or balance of minerals in soil. His trials and studies on plants and animals showed that **declining soil fertility was due to reduced organic matter and the imbalance or lack of trace minerals and major elements**. Poor nutrient crops were in turn responsible for animal diseases found in animals fed these crops/pastures.

The Albrecht soil test uses an acid stronger than plants produce. Many view the test results as the **mineral bank** in the soil. The mineral applications required to bring soil mineral levels to the desired Albrecht levels are often cost prohibitive.

Reams Method

Cary Reams was a scientist working as an agricultural consultant in the US. Cary Reams realized that that traditional soil tests did not give an accurate picture of a soils fertility level. He realised that pH was a measure of electrical resistance in the soil. He observed that soil pH would fall into place naturally once the various nutrients were balanced. The Reams test uses a weaker acid which mimics acids released by plant roots. This is viewed as measuring the available nutrients in soil for plant growth (uses the LaMotte testing Kit and the Morgan procedure). He tested calcium, phosphate, potash, nitrate and ammoniacal nitrogens, ERGS (conductivity) and various trace elements.

Mikhail Method (MM)

Edward Hanna Mikhail began his career as an agronomist in Egypt and moved to Australia in 1967. He worked in the State Chemistry Laboratory as a research scientist focusing on the relationship between the chemical and physical properties of soils. In 1980 he established the SWEP Analytical Laboratories in order to better serve the agricultural community by applying his principles in soil, plant, animals and human relationships.

By 1986 he developed “The Mikhail System” which was a result of his research into soils around the world. Mikhail believed that the soil was a living system of three functional interactive components physical, nutrient and biology. Like the human body you first start with the skeleton, in soil this skeleton is made of: calcium, magnesium, sodium, potassium and hydrogen in the correct proportions. Next you added the body, in soil the body is built from the nutrients: nitrogen, phosphorus, potassium and sulphur. Then you need vitamins and trace elements in correct proportions and healthy micro-bacterial flora.

The MM focuses on the cation balance first, then nutrients and then the soil microbiology. The MM is the only one to calculate an adjusted CEC based on the soils organic matter (OM). This is because the OM roughly contributes 0.5meq H+ per1% of OM. This gives an adjusted CEC for the soil which the makes calculations to balance the soil more reliable.

The MM extracts calcium, sodium and potassium using ammonium acetate or ammonium chloride (depending on presence of free lime in the soil).

Two years ago SWEP introduced a means of measuring microbiology. They found in their tests five main groups: lactic acid bacteria, actinomycetes, photosynthetic bacteria, fungi and yeasts. They developed agar cultures to selectively grow these groups. They found the same groups were always present in the soil but in different active amounts. Mikhail has analysed hundreds of soil tests and correlated CEC total to active bacteria percentages and found the ratios of different groups remain consistent. This means that the CEC does influence the amounts and groups of bacteria present in the soil or visa versa. Mikhail’s work has not yet been published.

Evaluation of Chemical Soil Tests

None of the tests can predict the mineral reserves present in the soil biota which becomes available to the plants once they have been digested by the soil micro-organisms. The tests also do not allow for mycorrhiza facilitating plant mineral uptake. GW suggested that a geological mineral test (which generally involves two strong acid extractions) would give a better indication of total minerals present in the soil. It would then depend on how healthy your soil biology was as to plant mineral availability.

Many biological consultants believe that calcium, phosphorus, magnesium and boron are the most important elements in BF. If these are in abundance crops and pasture produce well and have a high nutrient value. The calcium is important as it plays a major role in the uptake of elements. Phosphorus is the energy mineral. It is the basis of ATP (adenine triphosphate), which is an energy carrying molecule for all chemical reactions in the mitochondria which is in all living cells. Magnesium is the mineral catalyst in plant chlorophyll and therefore a key player in photosynthesis. Boron is a calcium synergist. Calcium does not function efficiently without boron. Boron is also involved in the sugar transfer in chloroplasts, which contain chlorophyll. The desired ratios of elements are given by all the different soils tests. Most important ratio being the Ca: Mg ratio. Some people believe that you can only correct these ratios and amounts by addition of the elements to soil or foliage. Others believe that the soil microbiology alone will take care of the microenvironment surrounding the roots of the plants (rhizosphere). The rhizosphere can have the desired pH and mineral ratios for the plant despite surrounding soil pH. Most people I visited had addressed the big imbalances if it was economical to do so. It is worth noting here that some people add minerals at greatly reduced amounts to the soil in a biologically active form i.e. minerals are added to the compost some time before spreading. Compost has far more cation exchange sites than clay and holds onto the cations added.

Another point to note is that Australia has very old weathered soils and our mineral content is not the same as the relatively young glaciated soils of Europe and North America. One speaker says that she does not think we need to add any minerals to our Australian soils and that the biology will access all minerals required. Arden Andersen said that mining assays may show the soil has adequate levels of minerals , but he could not risk multimillion dollar crops in hope that the minerals would be accessed by the soil biology. I also met a vegetable grower in Australia who lost nearly a million dollars pinning all his hopes on using the microbiological approach only and ignored the chemical parameters.

Biological Tests

Testing for soil microbiology can be done in a number of ways

- Direct microscopic examination in solution or gram stains
- Selective agar cultures
- Indirect by measurement of enzymes produced by certain groups
- DNA analysis

The SFW laboratories have attempted to give a detailed account of what is in the soil by direct microscopy. I visited the laboratories in Lismore, Australia and a new lab being opened in the UK at Laverstock Park. Laverstock Park is a biodynamic farm owned by entrepreneur Jodi Scheckter. They have cattle, buffalo, pigs, sheep, poultry, crops, vines, vegetables, a dairy, an abattoir and a compost site. They also aim to produce biofuel from farm waste in the future. The lab has been set up to not only to process Soil Food Web samples but to process the mandatory tests required in the abattoir and the dairy produce. All products are sold through their on-farm shop.

Microscopic examination of soil samples

Soil Food Web Labs measure diversity visually through a microscope using morphological shapes to group bacteria. Fungal diversity is measured by looking at shape, colour, strand diameter, presence of septa and filamentous form. SFW

class beneficial fungi as fungi having a diameter greater than 3microns. (This is not proven as scientific fact). Quantitative measurement is via slide grid field counts. The preparation of sample such as weighing and dilution is critical in this case. They measure active bacteria and fungi by adding fluorescent molecules to the sample. Active organisms take in the dye and fluoresce. Protozoa are visually counted in slide fields and classified into flagellates, ciliates and amoebae. The SFW laboratories offer one day courses where they teach you to use the microscope and analyse your soil, compost and compost teas. It also allows quantitative and qualitative analysis of compost teas. The SFW tests are not recommended by the few university academics that I spoke to: Jill Clapperton, Dan Sullivan, Gupta V, and Lyn Carpenter Bloggs.

Many conventional scientists query the validity and usefulness of these results. But many people making compost teas and biologically farming felt that it was invaluable as a method to monitor products applied to their soil. I had the experience where I was sold a brewer, food and bacterial/fungal inoculant as a kit. It was only that I was able to monitor the compost tea with an oxygen meter and microscopically examine compost tea samples that I found the brew was very poor if not toxic as it had gone anaerobic and was jam packed with bacterial rods, no diversity!

SFW also count and identify nematodes, mycorrhiza and micro arthropods. Absolute numbers are going to change according to soil moisture, temperature, carbon source, chemical treatments and time frame but it gives you snapshot in time.

EI proposes that manipulation of ratios can alter weed presence. I contacted the Australian and Corvalis SFW labs for names of long term (>3years) practicing SFW farms. Unfortunately I was not given contacts fulfilling this criterion in Washington State. So I could not visit any long term SFW practising farms.

Figure 9: Organisms in Different Soils and Different Foods

Organism numbers in different soils				
Organism Assays	Agricultural Soil	Ag-Rhizo-sphere	Healthy Soil	Healthy Rhizosphere
Total bacteria (#/gram dry soil)	1 X 10^{6}	1 X 10^{12}	6 X 10^{8}	1 X 10^{12}
# of bacterial species/g soil	5,000	5,000	25,000	25,000
Total fungi (ug per g dry soil)	5	20	150	300 – 500
# of fungal species /g soil	500	?	8,000	8,000
VAM colonization	0	0	55%	55%

← Bacterial Foods →

← Fungal Foods →

Simple	More Complex	More Complex	Very Complex
Amino Acids	Proteins	Hormones Vitamins	Fulvic acids (Minerals)
Carbohydrates	Chlorophyll	Fats	Humic Acids
Sugars	Polysaccharides Amino sugars	Lipopolysaccharides	
		Cellulose	Lignin
Organic Acids	Fatty Acids	Waxes	

Source: Dr Elaine Ingham. *“True Fertility Workshop.”* 27th February 2006

Mid West Bio Systems of Missouri, USA measure: heterotrophic (aerobic), anaerobic (grow without oxygen), filamentous fungi and yeast, actinomycetes and nitrogen fixing bacteria.

I did not illicit how these were determined. Mid West Biosystems measure these ratios and say healthy soils should contain a 10:1 ratio or greater of aerobes to anaerobes. Soil that is compacted and has little air and will have a lower ratio as conditions will favour anaerobes. It is also worth mentioning that some bacteria can switch from aerobic to anaerobic –called facultative anaerobes.

SWEP Laboratories (Melbourne, Australia) measure groups similar to Mid West Biosystems as previously discussed. They use different growth agar medias to grow specific groups. A quantitative and qualitative result is then given.

Other soil tests measure microbial activity. This is usually measurement of an enzyme dehydrogenase, which is produced when bacteria break down carbon. Jennifer Reeves said studies have shown this enzyme is markedly reduced when pesticides and herbicides are added to the soil.

Ray O'Grady from Lismore Australia, suggested other parameters that could be measured by BF in future. He felt that it was important to measure soil biology and carbon types. Ray said that the fungal by-products such as glomalin (produced by VAM) can be measured and the numbers of trophic nematodes. Ray talked about looking at carbon classification based on its longevity in the soil. Three types are classified, labile, intermediate and stable carbon. Labile carbon such as cellulose remains in the soil for up to twelve months. Intermediate carbon is glomalin which lasts up to ten years in the soil. Stable carbon remains in the soil for hundreds of years . I found this exciting news as it explained why compost and mulches can disappear from your soils quickly. **If we can target increasing intermediate and stable carbon types along with labile we will make progress in increasing soil carbon and its' beneficial effects!!!**

Single Test for soils and plants

I visited India to look at chromatographical analysis. Dr Perumal and his associates at Muruappa Chettiar Research Centre questioned the need for different tests for soil biology and chemistry. This test was modified and calibrated to be used by farmers onsite. It had to be low cost, easy to perform, have a rapid result and high level of reliability. Their test measures N, P, K, bacterial activity and humic acid content. A circular piece of chromatographical paper is inoculated with a silver nitrate solution. A solution from soil is added to the paper via a wick.

Three zones appear on the paper; the inner zone of the chromatograph depicts the minerals, middle zone the organic and outer layer the humic acid content.

Photo: Taken in Muruappa Chettiar Research Centre Chennai by C.Harvey

Dr Perumal's colleagues are calibrating against conventional tests so that a chart is being developed that will enable farmers to interpret their results on farm. The mineral data may be insufficient for biological farmers wanting to calculate CEC but the microbiological and humic acid results could be very useful. The test is also used to show the nutrient value of foods.

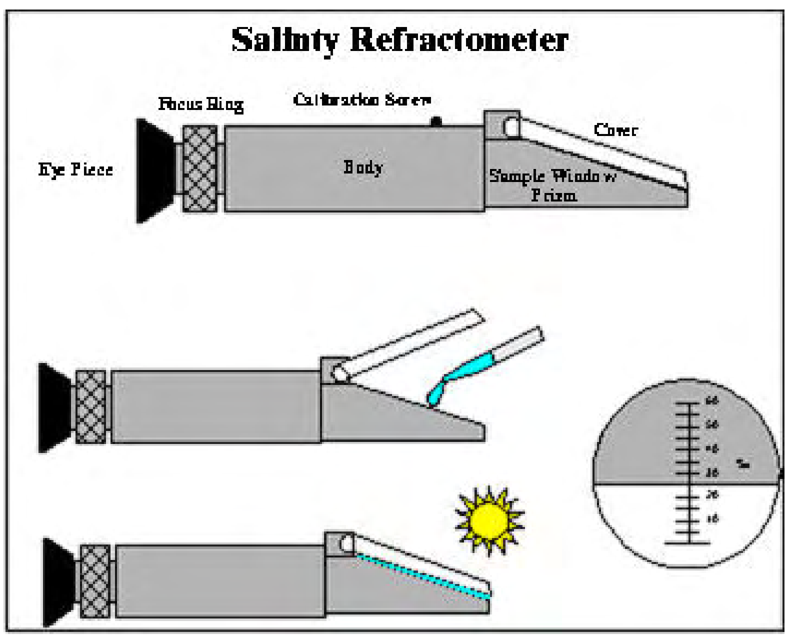
Plant Tests

Measuring plants gives indication of soil nutrients and overall health.

- Visual assessment of plant
- Refractometer: indirect measurement of soil's condition and fertility. Sap from plant is squeezed onto the refractometer. The sap solution contains sugars and minerals. The higher the sugars and minerals, the higher the refractometer reading (brix level) . There are tables of recommended brix levels for different plants. Generally for crops brix levels above 12 are excellent and brix levels below 6 are poor. Many farmers and consultants experience shows that insects won't attack plants with a brix level below 12. I spoke to a few farmers whose crops were unaffected by insects except on the perimeters when their neighbouring crops were attacked by insects such as Lucerne flea.

Brix levels change during the day as sugars are dependent on photosynthesis. Therefore levels are lowest in the morning and highest around midday. High levels of nitrogen fertilizers also affect the brix readings; this causes increased readings from free nitrates in sap.

Figure 10: Refractometer for Brix Readings



Source: Arden Anderson. *"Science in Agriculture"*

Plant tissue tests, done in conjunction with mineral tests can tell if there is a problem with uptake of minerals from the soil.

A Summary of Soil Tests

In summary I think soil tests are very useful for diagnosing problems and monitoring progress of your chosen biological treatment. It is advantageous to understand the tests so you can question recommendations advisors may give. You may choose to devise your own soil and plant treatment plans. You can collect quantitative and qualitative data from physical, chemical and biological tests. Be systematic and observe correct protocol when you collect samples. Keep good records of where and when samples were taken so that they can be repeated at regular periods. I saw many people had changed soil tests during the years and it made it difficult to compare results so if possible ensure samples go to the same laboratory and same techniques are used so that you can compare results over time.

Which Tests?

This is for the individual to decide. When I asked GW what he considered the most important test he answered "Nutritional test of the final product". Arden Andersen says "treat the patient not the lab test". Really this is the ultimate test, when you have food right you know that all the other parameters must be in balance!

Achieving the Theory

I think it is important to remember to" see what you are looking at". What is growing in your soil is also an indication of soil health. I have not touched on it yet but weeds are an indicator of soils problems. There are excellent books and information on what different types of weeds mean in your soil health parameters.

After gathering some baseline data of your soils you need to list the problems in their order of importance and look at how they can be changed. Consult with an advisor who preferably is not linked to a fertilizer company, but be prepared to pay for advice. Also talking to other like-minded farmers who are further down the biological road may help point you in the right direction. There are differences of opinion as to how to achieve the same ends. Some say that re-establishing the soil microbiology will rebalance the minerals, others say look at soil conductivity CEC and others say rebalance the minerals and provide food and the microbiology will reappear. The latter seems more common and supported approach. As with most things often a multi-pronged approach is best.

Biological Farming Methods

The following are some biological farming methods that I encountered. I have not reported on the use of inorganic fertilizer in BF. Jo Scammel wrote an excellent report which included excellent data on this. Her report details are in references, it is most worthwhile reading. Many BF do use herbicides, pesticides and fungicides but alter the application rates and add other products to reduce detrimental affects on the soil biology. I have focused on methods to improve the soil's physical, chemical and micro-biological parameters, such that the soil itself produces the nutrients plants require. It is interesting to note the following comments given in relation to soil nutrients.

" *Ideally 80% ,of nutrients for biological life come from the air and about 20%come from the soil or diet*" Arden Andersen

"*70% of the nitrogen is not in the humus but in the microbial protein*" Krasil'nikov

Green Manuring/Cover Crops

Green manuring is producing a crop that is incorporated into the soil before maturity. This green material feeds the soil food web. Cover crops fulfil a wide range of uses: reduce fertilizer costs, reduce the need for herbicides and other pesticides, enhance soil health, prevent erosion, conserve soil moisture and increase soil organic matter. Leguminous crops can add 140kg N/ha within 10 days of plough down. Work has been done in Australia, especially WA and I am keen to learn more of the results. Providing carbohydrates for soil bacteria increases your bacterial population also increases the soil nitrogen reserves.

Gerald Wiebe in Winnipeg uses green manuring as an integral part of his cropping program. He has a 90 day growing season and annual rainfall of 375 to 500 mm. For only 150 days of the year is the ground unfrozen. GW has a three year crop rotation including a year he does not reap a crop. He markets to niche organic markets and is paid above the commodity price for his superior nutrient dense product. His program is based on the following plant rotations:

- Year 1 Spring: Plants a green manure crop, uses 2 crops to obtain different exudates (thereby increase microbial diversity) and to produce large biomass to suppress weeds. Incorporates the plants using discs into 15 cm.
- Year 1 Winter: Six weeks post green manure incorporation sows rye.
- Year 2 Summer: Harvests rye. Incorporates stubble with compost extract, fish hydrolysate, molasses and water.
- Year 3 Spring: Sows Flax with added mycorrhiza. May add calcium and citrate. Mycorrhizas increase the crops flowering length and seed set. Has increased grain yield and reduced stalk production.

Green manuring. Photo courtesy of G. Wiebe

Jill Clapperton of Lethbridge Research Centre also advocated cover crops and green manuring. She also preferred no till methods but did comment that soil can recover from tillage if soil has good organic matter. Jill described green manuring as a compost tea in situ.

Stubble Retention

To gain the greatest benefit from stubble it needs to be rolled/incorporated on or into the soil. Left standing much of the carbon oxidises and contributes to greenhouse gases. As mentioned above incorporation of stubble with compost teas/extracts and foods greatly aids stubble breakdown and the retention of nutrients in the soil. Alternatively animals can graze the stubble and return organic matter to the soil in manure form.

Upper: Stubble prior to any treatment,

Lower: Stubble at two weeks post treatment with compost tea, fish hydrolysate and molasses. Note fungal growth and decomposition of stubble.

Photos courtesy of G.Wiebe

Figure 11: SFW Analysis from GW Farm Compost teas sprayed on stubble and incorporated into soil.

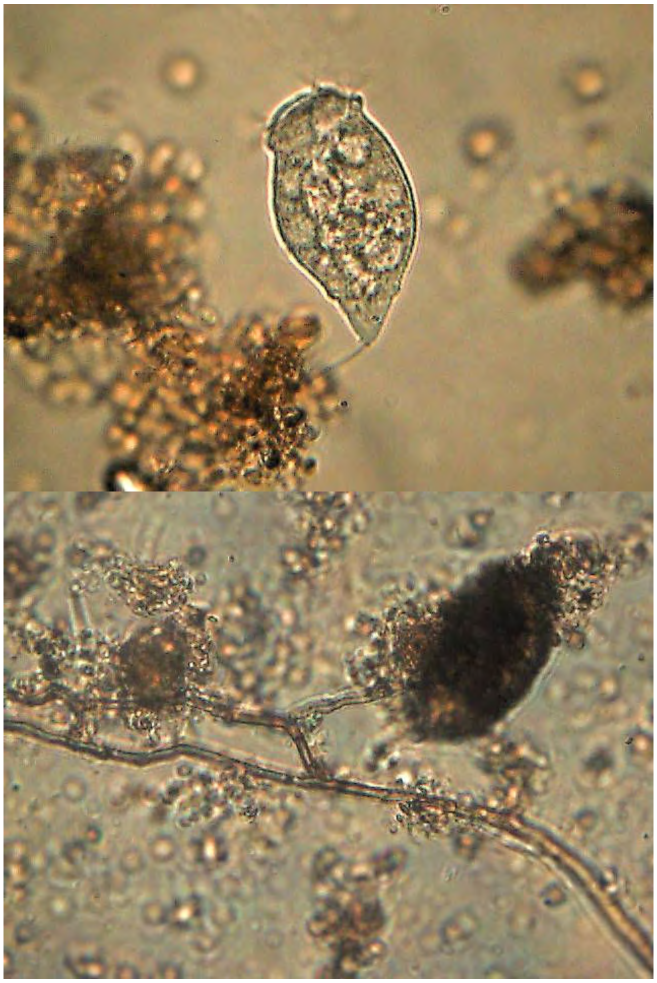
SFW Analysis	Active Bacteria	Total Bacteria	Active Fungi	Total Fungi	B: F Ratio
Before Compost tea	32.1	239	6.9	77.5	3:1
After Compost Tea	62.9	1112	32.5	278	4:1

Compost Teas and Compost Extracts

Compost tea is: a **brewed** water extract of compost. In order to increase microbial biomass and activity other foods are added and the water must be kept oxygenated.

Compost extract is: water based extraction of the soluble minerals, humic substances and microbes that are in the compost.

Compost teas are usually brewed over a period of 24 hours or more. Some teas are heated to increase activity but some advisors recommend teas should be brewed at soil temperature so that microbial populations grown in the tea are suited to the current soil conditions. (Brewing at 12C usually sees very slow growth). Brewing conditions may favour certain populations growth and be the demise of others. I certainly have seen my fungal populations deteriorate in our brewing process. The process must be monitored carefully to ensure the solution does not become anaerobic, direct microscopical examination allows quantitative and qualitative assessment of the compost tea.



Upper photo shows bacterial microaggregates and fungi and a large central protozoa.

Lower microscope photo shows a branching fungal hypae ,yellow colour indicates humic acid production within the fungus. Many bacteria present and microaggregates

Microscope photos per Cathie Harvey

Compost extracts are used because larger amounts of compost liquid can be produced per time period (uses more compost) compared to compost tea. Extracts are said to maintain the original microbial population. No food sources are added initially, allowing microbes to remain inactive, thus conserving oxygen. (I do wonder that there is not death and population change as solutions go anaerobic but E Blosser assured me this was not the case). This extends the life of the solution to 10 to 14 days. When sprayed onto destination, foods are added to the solution to reactivate the microbes in the extract. Compost teas and extracts are used for 3 reasons:

1. add microbial populations back to the soil. (no research to support changed microbial populations with soil additions of compost teas/extracts)

2. introduce large numbers to perform specific task such as facilitate stubble breakdown

3. Disease control. Some people use compost teas to control specific diseases. Electron microscopy pictures show healthy plants have a minimum of 60 to

70% of their leaf surface area covered with fungi and bacteria. These act as a physical and chemical barrier to pathogenic organisms. The theory is that spraying compost teas on the plants will reintroduce good microbes which will out crowd the bad ones. Research by Lyn Carpenter-Bloggs supports this. Mike Harrington uses compost teas for disease control in turfs and pastures with great success. Ben Dowling in Mt Gambier is a biological consultant and supplier of compost teas. He has had success using compost teas and foods in prevention of diseases such as leaf curl and prevention of root feeding nematodes. One orchard he has tried to prevent black spot on apples has failed but that could be in part due to orchard also using copper and sulphur sprays which are fungicidal in neighbouring trees. Ben highlighted that different areas have different disease pressures and environmental pressures that may account for different successes or failures.

I visited a number of consultants who have used compost teas/extracts with foods in their programmes and have had excellent results in crops produced. I have not spoken to any that have only applied foods without the compost addition to act as a control.

Research is being done by Jennifer Reeve at Pullman University in Washington State. Results are not yet published but wheat seed treated with compost extract and nitrogen grew better than wheat only treated with nitrogen in a vermiculite material.

Lyn Carpenter–Bloggs work is growing different micro-organism communities for specific disease problems. This is to produce a commercial product for say bacterial blight. She said the success is via the competition these communities provide on the plant surfaces.

Compost quality is critical to quality of extract or brew. Most people had tested their compost and compost teas using SFW analysis.

Mike Harrington in the UK was considering using EM (Effective Microbes) solution in place of compost is in his compost teas. He felt the populations in EM could do the same as those found in the compost. Mike is having great success using them for odour control in intensive pig and poultry units and compost sites. Certainly there are many farmers using EM to aid composting. Ben Dowling also found that EM improved fungal growth and compost breakdown when added to his compost. Heather Goricke in the UK markets bokashi, this is a cereal soaked with an EM solution. It is sold as an additive to food scrap buckets (to remove odour) and compost.

The general technology for EM was developed in Japan. It was largely developed by Dr Teruo Higa. It is a combination of microbial species of beneficial bacteria including lactic acid bacteria, photosynthetic bacteria and yeast. These micro-organisms are natural and commonly found in nature and have powerful anti-oxidative properties. There are anaerobic and aerobic species. EM's are meant to be obtained from each countries indigenous populations of microorganisms. Besides adding to composts they have been used as soil treatments, waste treatments, odour control, water remediation and even to clean moulds in dairies and through pivots! You may note they are some of the same classes of micro-organisms tested for in the Mikhail and Mid West Bio systems tests.

Compost Tea Brewers and Extractors

I am including a brief section on this as it easy to buy expensive inappropriate equipment. This is of interest to those interested in compost tea extraction or brewing.

There is a huge variety of these ranging from inexpensive homemade ones to high cost manufactured units. This is where if you are going to be making your own compost teas you can make expensive mistakes. This is an area I urge you to comprehensively research. When looking at brewers consider:

- Where and when you will use teas or extracts
- Calculate amounts in litres that you will be applying and daily desired applications i.e. capacity of unit required and extract vs. brewing.
- Analyse cost of purchasing extracts/teas to producing your own and developing expertise to produce them yourself.
- Look at on farm infrastructure to handle biological foods, if you are cropping you may be handling large amounts eg. 25000 litres of fish hydrolysate per season. Think how will you mix and store those amounts?

- Do you have a boom spray with suitable set up to spray out teas eg pump type, nozzle sizes, filters? Is this boom-spray used for herbicide and pesticide applications? If so tank residuals can be toxic to the compost tea if not thoroughly cleaned out.

Below I will describe the different brewers that I saw. There is a big variation in capacity, quality and quantity of extract and tea produced, ease of use and cleaning and cost. Some of the units will come with brewing results.

We have two compost teas brewers on our farm. One uses a diffuser to bubble air from a spa pump into a cone tank. The bubbles vigorously rise and pass through a mesh bag on the surface, which holds the compost. It is a 1500l tank so we are limited to brewing that amount which we found is quite inadequate for our needs (1000ha). The spa pump burnt out after 8 brews. They are not designed to run for more than a few hours at a time and brewing times can be up to 36 hours.

The second brewer consists of an inverted stainless steel T piece which has the compost bag attached on the end of a diffuser. Air is blown through the compost in the bag. The assembly fits into 1000 litre totes. Maximum extraction is 7 litres of compost in 1000l per hour. This is not enough capacity for compost tea brewing if teas are being put on large areas.

Ray Grady of Smartbugs in Australia has designed a different system. The compost is placed in a tank with a special slit design diffuser, which makes smaller bubbles and therefore increases surface area and oxygen carrying capacity. The diffuser removes the micro-organisms and aggregates from the compost. This mixture is then poured into a vibrating separator. These screens filter the extract and leave behind the solids so that the final extract /brewer will not block nozzles. The extract is then pumped into a hyperbolic tank (no dead air spaces) and aerated. This has capacity of 3500l. Ben Dowling who sells compost teas uses this system.

Gerhard Wiebe and Ben Mead use a hydro cyclonic extractor, which uses vortex technology that quickly oxygenates the water made by Sabino Cortez. This system extracted and brewed with the same equipment. High levels of dissolved oxygen are created by centrifugal forces pulling ambient air from the atmosphere through the venturi effect the vortex of liquid creates. As the air is pulled in, the airflow and the geometry of the vortex reverses 90% of the liquid back out the top. The vortex is then made up of two spinning columns of water travelling against each other in opposite directions around a core of air creating a wrenching cyclone that extracts and brews compost tea. These systems can produce1600 litres of extract an hour.

Figure 12: Results from a GW Compost tea Brew

	Active Bacteria	Total bacteria	Active Fungal	Total fungal
SFW Recommended Results for Compost tea	10 – 150	150-3000	2-10	2-20
GW Compost Tea	77	12,416	365	524

Compost

Compost is the stabilized and sanitized product of microbial and thermophilic decomposition of plant and animal material. In the process of decomposition the organisms release metabolic heat and metabolic products. The mature compost consists of humus, nutrients and micro-organisms. As with most procedures there are many ways to produce compost. Broadly speaking there are 3 types of compost:

- aerobic/thermal compost Heats to 55 C. Needs to maintain this temp for 3 days to kill weed seeds and pathogenic organisms. Material is turned so that pile maintains oxygen for microbial breakdown. Good compost has high humic acid content and microbial populations. Can be completed in10 to 12 weeks

- Worm composting (vermi-composting): usually compost worms (not earthworms) such as red worms consume the bacteria, fungi, nematodes and protozoa growing in and on the organic matter. The worms mix, aerate enhance micro-organisms growth and produce vitamins, hormones and disease suppressive chemicals. Doesn't remove weed seeds

- Static Compost: material is broken down anaerobically. Can reach very high temperatures and produce anaerobic odours and volatile gases. Usually more loss of compost mass and takes longer 6 to 12 months. It is turned only in last 2 weeks. Used for carcass disposal

Compost can be spread and incorporated on soil and provide an excellent source of nutrients. I visited a number of compost sites. Most compost sites were a means to rid waste from municipalities or farm origin. The money was made from taking fees not selling the compost. This was always poor quality compost, usually burned carbon produced at high temperatures. It did provide organic matter but was not highly humified or microbially diverse compost.

I did attend Mid West Bio-Systems course on producing highly humified compost. This compost is high tech compost! The whole process from start to finish is monitored and tested. Compost is produced in long windrows; it is turned and watered with a special windrow turner. It is a 3-day course to learn the intricacies of producing highly humified compost. They have a comprehensive test to grade the compost produced. The high quality graded compost is retailing in the US for $150/t.

There are people in Australia using their method and inoculants to produce this compost. Even at a ton per hectare it is not cheap and it is recommended on high quality crops to be spread at 8t/ha. I spent 5 days with these lovely Mid West Bio Systems people who showed me around their farms that were using the compost. The best results were in horticultural greenhouses where plants were planted in the compost.

An Amish Greenhouse. The tomatoes were planted in compost and watered No other foods or chemicals added.

Photo by C Harvey Missouri

Source: Amish Farm Missouri C Harvey Nuffield Trip

The farms I saw trying to produce compost were struggling to find the time to produce high quality aerobic compost. I did see in Great Barrington estate lovely 18month old manure and straw piles invaded by worms that had formed great worm compost. Nuffield scholar Richard Steel sent his cattle bedding waste to a mushroom farm and it was returned to him after used as highly fungal compost.

Richard Steel's Fungally dominant compost after straw used in mushroom farm.

Photo:CHarvey Pershore

Bioactive Materials

Many organic and biological farmers will be familiar with a number of soil conditioning products. Theses are used all over the world. When purchasing these products ensure that they do not contain substances that will prevent microbial growth eg: added sulphur to molasses, fumigants, and sterilants. If in doubt you can add the bioactive material in question to a microbial solution. Using a microscope you can look at the solution before and after and monitor microbial activity.

SWEP labs of Australia have done some research into micro-organisms response to addition of bioactive substances and it is worth reading. Their research shows that different soil groups react depending on rate and product applied. Recommendations of foods and application rates are given in their farm soil test reports.

Fish Hydrolysate or Emulsions

This is a broken down fish product. There is a huge variability in content. The best fish products are from the whole fish with the oil content still present. The oil is said to be a fungal food and desired level of 15 to 20%. I was taken aside and lectured on the importance of buying a good fish hydrolysate by GW. The following are his comments.

Fish Emulsion usually means not all parts of the fish are present (fish often gutted at sea), it has been heated to a high temperature, oil is removed and often extrogenous nitrogen added to it to give high nitrogen content. This is not a good source of fish product.

Fish Hydrolysate is considered superior .The breakdown process is by enzyme digestion, it has not been heated to a high temperature so that proteins are not denatured. The product is stabilized with phosphoric or citric acid. In the US the source is shark and sells for $2.50/gallon.(Aus 91c/l). In Australia fish hydrolysate can be sourced direct from wholesalers for a similar price plus freight. This is shipped from Port Lincoln or WA. The SA source is from tuna fish. The fish hydrolysate is acid and must be diluted to at least 1:4 parts with water.

The fresh water fish in the US often have a high heavy metal content.

Molasses

Molasses is used to boost soil bacterial activity by providing sugars for energy. As with fish you need to check additives to the product. We have found handling and mixing molasses a problem. The addition of calcium nitrate to molasses greatly reduces its viscosity. Alternatively many people in Australia buy Molofos, this is molasses with 3% nitrogen added, it has improved handling properties compared to plain molasses.. It is difficult to heat molasses with an element, as it is a poor conductor of heat. Depending on amounts being mixed you can add it to hot water but flow rate in a southern winter is very slow. It behaves almost like a solid liquid.

Humates

Humates are produced by liquefaction of brown coal. This coal-based product is added to soil to feed fungi and some bacteria. Because of its CEC capacity it is good to help ameliorate salts in soils. Humates can be purchased in dry or liquid form.

There is a wide range of product formulation. The labelling usually states humic acid content. Most have a content of 12% but the Australian Omni product has 26% humate content. There is a dry form which dissolves with hot water. Personal experience handling humate has been messy. The liquid form must be thoroughly mixed as it sediments out and blocks boom jets. It has been said that the source can affect the humate value eg. imports from China. Some farmers are spreading coal dust on their farms in Australia, this is much cheaper than buying the humate preparations but must be spread rather than added in liquid form. Unfortunately I have not spoken to any farmers who have spread coal dust to hear their results.

Worm leachate

Sometimes it is the solution drained from a vermi-compost heap. Other solutions are castings dissolved in water. Leachate contains growth stimulates to some groups of bacteria. Some say it stimulates fungal growth. SWEP laboratory research showed that it might be better than molasses as soil food as the microbial response was the same. At low rates worm leachate stimulated fungi and cellulose utilizers and at higher rates stimulated photosynthetic bacteria.

Mycorrhiza

Mycorrhiza is a filamentous fungi that can attach and penetrate plant roots. They form a symbiotic relationship with the plant. The fungi filaments provide the roots with minerals, nutrients and water. The plant in return provides essential sugars and nutrients for the fungi. The fungi produce compounds, which stimulate more root growth. The improved water and nutrient uptake alongside an increased root mass makes the plant a healthy and more drought resistant plant. Mycorrhiza produce compounds which dissolve insoluble minerals and thereby make these minerals available to the plant. Phosphorus levels affect mycorrhizal growth, the higher the soil phosphorus levels the greater the suppression of mycorrhiza. Tillage practices destroy mycorrhiza levels in soil.

There are three types of mycorrhiza; the one of interest to farming is the vesicular arbuscular mycorrhiza (VAM).

John Reeve a former farmer in the UK has been studying mycorrhiza for the past 25 years. He has run many trials showing the improvement to plant growth with mycorrhizal applications. John has published his results in a number of publications. John's trials show an average increase in plant mineral content of 25% with the addition of VAM to the plants roots .Also the ratio of Ca : P is maintained to 2:1 which is the nutritional ratio required for animals. Conventionally grown crops have an unsuitable Ca : P ratio.[3]

VAM are very fragile and need living roots to grow and exist. Tillage, high levels of raw manure (possibly by causing high levels of phosphorus mobilisation),high levels of phosphorus (optimum p level 32ppm.) all destroy or suppress VAM.

I visited a number of farms applying VAM to their seed crops. It can be made into solution and mixed with seed or trickled in with seeding in a clay carrier. Jill Clapperton said trials indicated the clay application to be more successful in VAM establishment. VAM is slow to reproduce; spores are produced in 9 months. VAM production is a complex process. Plant roots for healthy plants have 50% plus colonization of their roots with VAM.

[3] John Reeve

Top Photo: Fescue seed sown with out VAM .

Bottom Photo: VAM added to fescue seed when sown.

Photos: courtesy of Mycorrhizal Applications

New Edge Microbials are now commercially producing a VAM inoculant in Australia. One of the partners worked with CSIRO on VAM. Glomus Intraradices was isolated as the most general and infective VAM in Australian soils. VAM takes four to six weeks to establish in the roots before beginning nutrient exchange. It takes a minimum of six weeks or longer to set spores.

John Reeve related to me that the old farmers took sods from established pasture and placed them in new pasture to improve establishment. This would have inoculated the new pasture with mycorrhiza.

Biochar

Research has been done into using biochar (a charcoal-like substance) as a soil improver. This idea has been developed from research into Terra Preta soils. I spoke with Johannes Lehmann from Cornell University who has been researching biochar for many years. He has run research trials in Kenya, Zambia, Brazil and now a temperate area, New York State.

Terra Preta soils

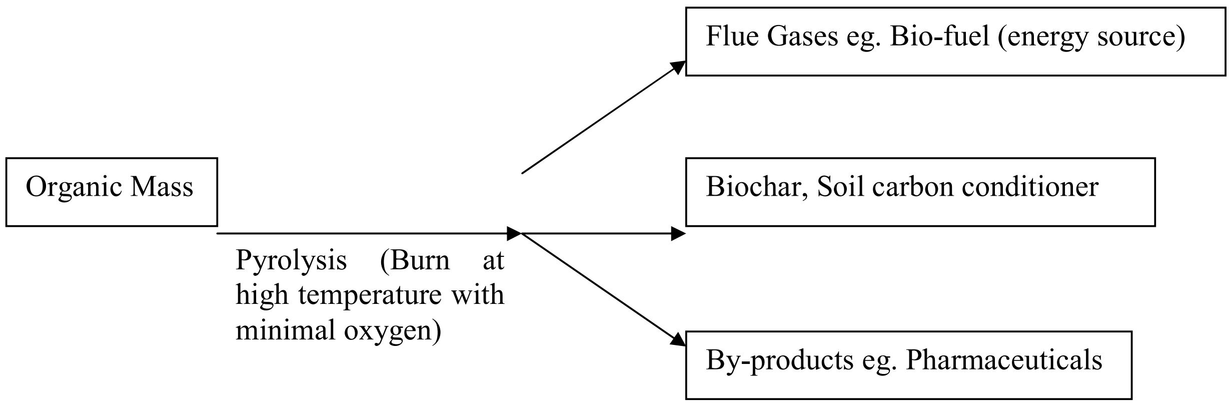
Briefly these are large areas of fertile soil found in the Amazon basin that were once part of large continuously cropped civilizations. This soil was found to be fertile after 500 years. Research has found that adjacent to Terra Preta the background soils are typical highly leached rainforest soils and are much lighter in colour. Analysis of this soil reveals a very complex nature. They found that the soil consists of charcoal, pottery shards rich in Ca and P (from cooking fish), shells, seaweed and microbiology. The mineralogy is the same between the Terra Preta soil and adjacent soil. The Terra Preta soils have different populations and greater microbial diversity compared to the adjacent soil.

Johannes Lehman is examining biochar's role and effect on the soil. Biochar has the highest CEC per unit of carbon. It is superior to clay and humus CEC. The other exciting characteristic of biochar is it's ½ life. It has potentiated carbon, which remains in the soil for hundreds and thousands of years. Biochar has also been found in mid west, Russia and Australia. Biochar provides a stable home for microbiology to live. In summary it

- Has highest CEC per unit Carbon (holds on to soil cations)
- Persists for hundreds of years (looking at few applications) (carbon from humus oxidizes with in 1 to10 years)
- Provides stable home for microbiology to prevent leaching
- Increases carbon content

Biochar could be used in agriculture, especially biologically based systems. It is being used in Africa and South America very successfully. Trails have shown crop yields increase from 10 to 300%. Not only are yields increased, but different crops can be grown.

Biochar production can be done on a large scale commercially. The production of biochar is:



The process is Carbon neutral or C negative (actually draws CO2 from atmosphere). It is a more carbon efficient process then ethanol production. Johannes has calculated that a strategy combining biochar and biofuels could ultimately offset 9.5 billion tons of carbon/year. This is equivalent to the world's current total fossil fuel emissions.

Biochar is produced when a material e.g. wood, manure, green waste, stubble is charred in minimal oxygen. The process though very old is very complex. and up to 65% of the carbon can be stabilized

Trials so far have revealed:

- Increases in long term soil carbon
- Increases in soil microbiology quantity and diversity
- Increases yields 10 to 300 percent
- Experimentation with rates still happening depends on many variables
- Size used 2 to 200mm
- Must be incorporated into soil
- Acts as a nuclei for clay and organic particle in the soil'
- Is not primarily a nutrient but improves soil physical, chemical and biological parameters
- Some trials putting biochar out through seeders.
- Acid soils can be ameliorated and fertilizer efficiency drastically improved.

Ray O'Grady has been investigating how biochar can be best used in agriculture. He said trying to source from producers overseas is difficult. In India the price is $100/T. (With recent further reading I have found in an 1855 Encyclopedia of Agriculture that addition of charcoal to soils had been trialed and was not uncommon practice in the UK and USA. They even described the different sources of wood used and yields. It was stated that the charcoal added to the soil produced increases in yields and was superior to just manure additions!)

Diesel Emissions incorporated into the Soil

I had the good fortune to meet Gary Lewis in Alberta. Gary is a farmer who has developed a system where the diesel exhaust is reincorporated into the soil. Therefore there are no diesel emissions released into the atmosphere.

Diesel Exhaust Gases are% by weight:

Nitrogen 75.2%

Oxygen 15%

Carbon Dioxide 7.1%

Water Vapor 2.6%

These are used as foods by the soil microbes. Gary has developed his system so he can manipulate the amount of nitrate into the soil. The plants use the nitrates and CO_2 as food and their activity is stimulated. Trials have shown that the soil pH moves towards 7 and that calcium becomes more available in the soil.

Gary has read extensively to understand plant nutrition and has used this to develop and understand his system. He has conducted trials, which show how the microbial levels have increased after the emission treatment. He is now consulting to other farmers. A portion of the fee they pay is going to fund research that Gary is funding Lethbridge Research Centre to run trials on the system and investigate the effect on the soil. Gary has a monitoring system that is used to set each tractors emissions to most desirable proportions, farmers keep detailed records to aid in developing a data base for this system.

Another very innovative project Gary has initiated is the *Bio-Agtive* CO2 Exchange Pilot Project.

“The idea behind this project is to offer our 200,000 beta group acres *BioAgtive* “CO2 acres under license available for public sponsorship by consumers in an urgent education campaign about CO2 sequestration as a method of reducing greenhouse gases and global warming, while supporting our company’s innovative technology and the end –users of it.”

Consumers, who buy “CO2 credits”, offset their own use against the farmer’s acres using the diesel emission incorporation. The money they pay for this credit goes to the farmer of the land, Gary’s company and the government. They wish to educate the consumer to make a connection in the consumers mind between their CO2 emissions and how that can be offset elsewhere.

Gary says research done predicts that consumers will voluntarily purchase the cards to help reduce greenhouse gas emissions. Unfortunately I did not get to view his system in action.

Gary has some farmers beginning to use his technology in Australia. Gary has set up the programme to have farmers feed back their experiences and findings and then share this knowledge with all other farmers in the group around the world.

Conclusions

I have tried to give a fairly comprehensive review of ways to quantify and qualify biological farming practices .To do this I spent much energy in researching the science behind the soil! I believe that the farmer must have a good understanding of the basic science principles of the soil. AA said that he considered the topics mandatory studying for farmers. As I think became obvious, the testing in biological farming is not uniform. Many people are coming at it from all directions thinking that they are on the “right” path. My ultimate aim was to pool as much of this information together so that others considering the biological path could get an overview of the topic. I tried to gather scientific data and that is archived in the references. I was disappointed that prominent methods being advocated often state results that are not published or available for peer review. There is no reported methodology, statistical analysis or discussion. In saying that, I did see farmers who kept good records of their farming and could show changes in their soil tests.

I did look at biological practices and see how, what, why people were engaging in their practices.

My ultimate aim is to improve our soil CEC, soil food web and increase our intermediate and stable soil carbon supplies. I have learnt many more ways to do this on the study tour. The new information I have learnt about (which is often old forgotten information) is just the beginning of an exciting learning journey.

Recommendations

I recommend that everyone tackle biological farming in their own way. Knowledge in the soil parameters would be beneficial as previously explained in the report. Individuals need to assess where their soil is, look at the agricultural products they are producing and decide which are the best practices to adopt to enable them to bring their soil to full fertility and productivity and profitability. **They need to question what they are being told and sold.**

Personally I shall be investigating diesel exhaust incorporation, VAM applications, green manuring, stubble incorporation (using extracts and foods) and bio-char production and application. I feel production of high grade compost is not feasible for large scale cropping or pasture applications because of the large amounts required and the time and labour required producing it. This would be a different story for farms with large waste steams to deal with.

References

Primary

Andersen, A.B. (2000) *Science in Agriculture*. *USA:Acres*

Andersen*,* A.B*. (*1989 2004*)The Anatomy of Life & Energy in Agriculture. USA: Acres*

Blosser, E.(2007) *ACS High Impact Compost Workshop.* Wisconsin: Mid-Western Bio Systems

Department of Agriculture. (2000) *Managing Cover Crops Profitability Sustainability*. US :*Agricultural Network*

Ingham, E. (2004) *The Foodweb in Compost*. New South Wales: Southern Cross University.

Ingham, E. (2006) *True Fertility Workshop.* Victoria: Agrisolutions

Jones, C.E. (2006) *Soil carbon means water to me!!.* Border Rivers-Gwyddir CMA and Grain & Graze workshops

Jones, C.E. (2002) *Building New Topsoil .Armidale*: Stipa Native GrassesForum

Karuppan, Perumal V. (2006). *Alternative Analytical Technique for Determination of Soil Fertility*, Pennsylvannia: 18th World Congress of Soil Science.

Krasil'nikov, N. A. (2000) *Soil Microorganisms and Higher Plants.* Moscow: Academy of Sciences of the USSR

Morton,J.C. ed. (1855) *A Cyclopedia of Agriculture, Practical & Scientific*. Glasgow: Blackie & Son

Reeve, J. (1993) *Influence of Agriculture On Mineral Nutrition And Health*. UK: Reeve

Reeve, J. (2003) *The Roots of Health*. UK: Reeve

Scamell,J,(*2000) A Practical Investigation Into The Vitamin and Mineral Nutrition Of High Yielding Dairy Cows Nuffield Report*. UK :Nuffield Farming Scholarship Trust

Voison A. (1959 translated reprint1999) *Soil, Grass & Cancer*. USA : Acres USA

Zimmer, G. (2000) *The Biological Farmer. USA:* Acres USA

Web sites

http://www.amazingcarbon.com/

www.**bettersoils**.com.au/

http://www.biochar-international.org/

www.eminfo.info/

www.**soilhealth**.com/

www.**swep**.com.au

http://www.mycorrhiza.com/

www.bioagtive.com (diesel exhaust emissions info)

www.co2xchange.com

Interviews

The following is a brief list of some of the people interviewed.

Graham Harvey	Journalist	UK	Food Quality and farming
Simon Weaver	Nuffield organic dairy farmer and cheesemaker	Stow of Wold, UK	Organic Methods
Andrew Dilby	Organic beef, chickens and cropping	Barrington Park, Great Barrington, UK	Also made vermicast
Josephine Scammel	Nuffield integrated nutrition, soil, forage and livestock consultant	Kingstone, Ilminster	Lectured in an intergrated soil management course in Somerset
Ben Dowling	Nuffield Biological dairy farmer and cheesemaker	Ponsanooth ,UK	2006 Biological Farming
Vinodh Krishnamurthy	Laverstock Park Soil Food Web Lab	Overton UK	Biodynamic Farm, farm shop ,compost making
Caroline Drummond	Leaf Coordinator	UK	Linking environment and farmers
Heather Gorringe	Wiggly Wigglers Nuffield	Lower Blakemere Farm UK	mail order bird feed and compost worms ,bokashi
Louise	Nuffield Ag Lecturer	Tew farm UK	Diversified large estate
Municipal Composting	Large municipal composting site	Heretfordshire	Poor quality compost, dealing with taking
Mike Harrington	Biological Consultant	East Hendred UK	Consults to farms, golf courses Uses EM
Alan Down	Nuffield Nurseryman	Bristol UK	Uses compost teas
Stefan Leggenhagger	Organic dairy farm	Flawil Switzerland	Biodiversity
Xavier Bohy	Beef & cropping consultant	St –Martins France	Compost making
John Reeve	Farmer researcher in mycorrhizae	Forest of Dean UK	Lifelong study myc.effect on plant minerals
Peter Surman	Organic dairy farmer	Upton on Severn	Won the Milk Minder Award most profitable dairy in all categories
Richard & Anne Steele	Nuffield Dairy Farmer	Elmley Castle UK	Mushroom compost
Nick Finding	Dairy manger	Rainbarrow UK	Biological dairy incredible fertility results
Clive & Judith	Brown Cow Organics Dairy farm and yogurt production	Somerset	Award winning organic beef, yogurt, lamb
John Dibble	Conventional dairy	Stone Farm UK	Converting to organic
Gerald & Verna Weibe	Organic cropping BF consultant	Manitou Canada	Scientist /farmer Innovative BF excellent results
Edwin Blosser	Compost consultant Mid West BioAg	Brodhead Wisconsin	Compost course
Marvin Blosser	Organic dairy farmer Chicken contract rearer	Wisconsin	Making aerobic windrow compost
CircleAAA	Feedlot ranch	Missouri	Feedlot composting
Amish Farmers	Tomato production	Missouri	Growing tomatoes in greenhouses with no chemicals in compost
Rodger Kropf	Micro leverage turkeys	Hughesville Missouri	Sold high quality

			compost
Melvan Kropf	Organic dairy, chickens	Hughesville Missouri	BF soil test results
Walmart Supermarket	Supermarket	Sedania	No organic products. highly processed food
Wholefoods	Supermarket organic or products with out GMs	Kansas City	Very interesting products and marketing Opened a store in Knightsbridge UK
Wild Oats	Supermarket organic, non GM	Kansas City	As above.
Harold Perry	Biological potato farmer Nuffield	Coaldale Canada	Highest yields in district
David Lepine	Bio-Ag Ltd Agricultural Consultant	Lethbridge Canada	Biological agents
Larry Kawchuck	Microbiologist Lethbridge Research Centre	Lethbridge Canada	Developing phages to combat bacterial diseases in potatoes
Dr Frank Larney	Compost Research,Feedlot waste	Lethbridge research center	Composting feedlot waste
Dan Sullivan	Oregon State Uni	Oregon USA	Compost research soil microbiology
Jennifer Reeve	Biological fertilizers vs conventional	Washington State Uni .	Enzyme assays
Lyn Carpenter-Bloggs	Compost Tea Research	Washington State Uni	Production of marketable bacteria to combat diseases
Howard Leffer	Organic cropping	Coaldale Canada	Windrow Compost Designed own compost tea brewer
Green growth forum	Lethbridge	Lethbridge	Community consultation on energy plans for future
Dave Harris	Harvest Haven, organic beef ,eggs, fruit vegetables farm shop	Coaldale Alberta	Successful farm shop to sell all produce direct Static Compost maker Compost teas
Jo Mann	Dairy and milk ,Yogurt producer	Pitcher Bute Alberta	Hires a small milk factory to process own milk
Jill Clapperton	Soil microbiologist	Lethbridge Research Centre	Research into soil microorganisms and increasing soil carbon
Gary Lewis	N/C Quest Diesel Exhaust injection	Pincher Creek Alberta	Developed system to inject tractor exhaust into soil
Neil Fuller	BF Consultant Scientist	Sleaford UK	Scientifically monitoring work
Dr Perumal	Murugga Chettiar Research Centre	Chennai India	Developed chromotagraphical analysis for farmers use Researches Biodynamic vs conventional food nutrient quality
K Parimala	Centre for Indian Knowledge Systems		educating traditional farming methods to

			farmers. Use traditional varieties of crops
Johannes Lehmann	World authority on Bio-Char Researcher	Cornell Uni USA Visited Adelaide	Research around the world into Bio-char
Ben Dowling	Biologist BF consultant Potato seed producer	Mt Gambier SA	Uses EM ,compost teas
Ted Mikail	SWEPT Labs Mikail soil analysis	Melbourne Vic	Developed tests to measure CEC, developed ratios and microbiology testing
Ray O'Grady	Smartbugs Co	South Lismore Aus	Developed compost tea brewer, -developing Bio-char products